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# A MULTIDISCIPLINARY STUDY OF CARTAGENA BAY, COLOMBIA

## Part I. WATER MOTION AND RELATED PHENOMENA

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## FORWARD

Between 1975 and 1977 scientists at the Rosenstiel School of Marine and Atmospheric Science, University of Miami, were involved at the request of Colombian authorities in matters related to the apparent increasing degradation of the environment and resources of Cartagena Bay, especially those related to mercury and chlorinated hydrocarbon pollution. Local studies had been fragmentary and lacked the co-ordinated multidisciplinary approach needed to provide baseline data for development of a management plan for the Bay area. However, Colombian scientists, technicians and university students were dedicated and enthusiastic in wishing to protect and conserve the Bay environment and resources, and thus were anxious to receive help and advice. Subsequently two events pointed to the need for urgent action and these were: (i) in mid-1977 the closure of the local alkali plant (source of mercury pollution) and (ii) the findings of the FAO-Swedish scientific team on the sources, nature and probable extent of contamination of the Bay.

The International Sea Grant program became operational in 1978 and a proposal was submitted to that program for the University of Miami to assist Colombia, based on our earlier study of Cartagena Bay. The proposal entitled "Marine Resources and Environmental Sciences Training and Information Exchange Program in Colombia" was accepted for funding for a 2-year period from 1 November 1978 with a subsequent extension for an additional year (3 years in total).

The general objective of the project, through a cooperative training program, was to enhance the capability of Colombian scientists and technicians to better deal with environmental and resources problems in the coastal zone. The specific project objectives, on a cooperative basis were (a) to provide a short series of lectures/seminars with related discussion periods, on the principles of multidisciplinary marine resources and environmental studies of tropical coastal areas such as Cartagena Bay, as well as by using case histories from other applicable areas; (b) to provide on-the-job training in the design, planning, execution and coordination of field and laboratory programs to provide the data base necessary for development of management plans for the coastal environment and resources, through a broad-scale integrated study of Cartagena Bay.

The first project objective was achieved with the successful holding of the training course at the Colombian Navy's Center for Oceanographic and Hydrographic Research, Cartagena, from 17-27 April 1979. The course consisted of 40 one-hour formal lectures, four each morning, followed by 3-4 hours of informal discussion each afternoon in two interchanging disciplinary groups (physical/chemical and biological). Thirty-five undergraduate students and ten faculty from seven Colombian universities and one research group attended with an additional 20-25 persons (scientists, technicians, Naval Officers) present each day. Lectures covered fields of hydrodynamics, chemistry of sea water and pollution, marine biology/ecology, pollution biology, marine geology and public affairs. Some 21 instructurs were involved, 17 of them from Colombia.

The second project objective was to undertake, as a training program, a broad-scale integrated multidisciplinary study of the environment and resources of Cartagena Bay. The field work related to this study was completed in May 1981; analyses and interpretation of the data are continuing. This present report on "Water Motion and Related Phenomena" is the first to result from the overall program.

Support of the project from the International Sea Grant Program, NOAA, U.S. Department of Commerce, under Grant No. 04-8-M01-166 is gratefully acknowledged. In addition, the financial and technical support of various groups in Colombia should be recognized in particular the Comisión Colombiano de Oceanografía (CCO); Dirección General Marítima y Portuaria (DIMAR); Centro de Investigaciones Oceanográficas y Hidrográficas (CIOH); Fondo Colombiano de los Recursos Naturales Renovables (INDERENA); Fundación Universidad de Bogota Jorge Tadeo Lozano (Seccional del Caribe, Cartagena); Universidad de Cartagena. Sincere appreciation must be expressed to Captain de Navío (R) Josue C. Aguirre Serrano, who was Port Captain, during the preliminary and project phases of the study, for his unfailing support and advice at all times.

F. Williams
Principal Investigator

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LIST OF SYMBOLS

| | |
|---|---|
| $A$ | surface area |
| $C\ell$ | chlorinity |
| $C_f$ | bottom friction coefficient |
| $C_1$ | interfacial friction coefficient |
| $C_D$ | surface wind drag coefficient |
| $E_{ij}$ | eddy viscosity coefficients |
| $f$ | Coriolis parameter |
| $F$ | force measures |
| $g$ | gravity acceleration |
| $H$ | tidal range |
| $H_1$ | bottom layer depth |
| $H_2$ | surface layer depth |
| $K_s$ | conductivity |
| $p$ | pressure |
| $P$ | tidal prism |
| $q_{1x}, q_{1y}$ and $q_{2x}, q_{2q}$ | layer discharges in x and y direction |
| $Q_F$ | freshwater discharge |
| $S$ | salinity |
| $t$ | temperature |
| $T$ | temperature anomaly, Chpt. 3 |
| $T$ | flushing time, Chpt. 5 |
| $u,v$ | x and y velocities |

| | |
|---|---|
| $U_{10}$ | wind speed 10 m above surface |
| $V_F$ | fresh water volume per tidal cycle |
| $V_T$ | total volume of top layer |
| $\eta_i$ | bottom, interface and surface elevation i = 0,1,2 |
| $\rho$ | density |
| $\Delta\rho$ | density difference |
| $\tau$ | stress term |

## 1. Abstract

An interdisciplinary project is undertaken with the objective of training Colombian personnel in dealing with pollution impact in coastal and estuarine waters. This goal will be approached through the transfer of technology from University of Miami in the form of formal and informal short courses and practical experience by involvement in a baseline study of Cartagena Bay.

The accomplishments and findings described in this report result primarily from the hydrodynamic effort while water chemistry, biological chemistry, biology, and geology are described in parallel reports.

To introduce the Colombian trainees to coastal hydrodynamics a series of 10 lectures were presented in April 1979 at the Center for Oceanographic and Hydrographic Investigations (CIOH) in Cartagena. These lectures were followed by several seminars covering the theory, data collection, data analyses, and modeling throughout the duration of the project.

A field sampling program is designed to monitor the main variables; currents, salinity-temperature, tides and turbidity on a regular basis.

The collected data show that the hydrodynamic characteristics of the Bay are strongly influenced by the freshwater inflow of the Canal del Dique. During periods of significant canal discharges the Bay exhibits a two layer stratification. This stratification is of major importance in understanding and describing the flow patterns in the Bay

as driven by tides and wind.

A twolayer vertically integrated finite element model is adapted to the Bay and applied to typical tide and wind forcing conditions. The tides effect a slow flushing on the order of 10 days in the surface layer while minimal flushing is found in the bottom layer. The difference is thought to be due to the submerged sill at Boca Grande. On the other hand, addition of wind creates significant particle displacements in both surface and bottom, though in different directions.

The model provides a possible clue to the breakdown of the stratification during the dry winter months, through a tilt of the interface due to barotropic wind response.

Finally, new evidence is found that the water entering from Canal del Dique, though fresh, can dive under the Bay surface water due to its sediment load.

## 2. Introduction

Located on the Caribbean coast of Colombia, S.A., the city of Cartagena and the neighboring bay plays an important role in that country's economy. During the Spanish colonization period remarkable ocean engineering projects were undertaken in an effort to protect the city of Cartagena from the attack of pirates. A submerged rock wall, over a mile long, was erected across the northern entrance to the Bay at Boca Grande, Fig. 2-1, to keep ships from entering. This wall is still in place and is an important hydrographic feature in that it limits the depth through which Bay water can exchange with the ocean to one or two meters. Inside the Bay, the water is quite deep 25-30 m except close to the shores. This characteristic along with good natural protection against large waves make the Bay an excellent harbor. The narrow inlet, Boca Chica, in the south is close to 20 m deep and serves as the navigation channel for ships entering and leaving the Port of Cartagena. Given these advantageous conditions it is not surprising that the Port has become one of the largest harbors of Columbia. A number of industrial plants that depend on the shipping facilities have developed along the east coast of the Bay. The shoreline to the north is heavily developed into residential, commercial and resort type communities. The remaining shoreline to the south and on Isla Tierra Bomba is relatively undeveloped with small villages only.

Tha bay is approximately 14 km long and 6 km wide with an average depth of about 20 m. It is irregularly shaped and has several small

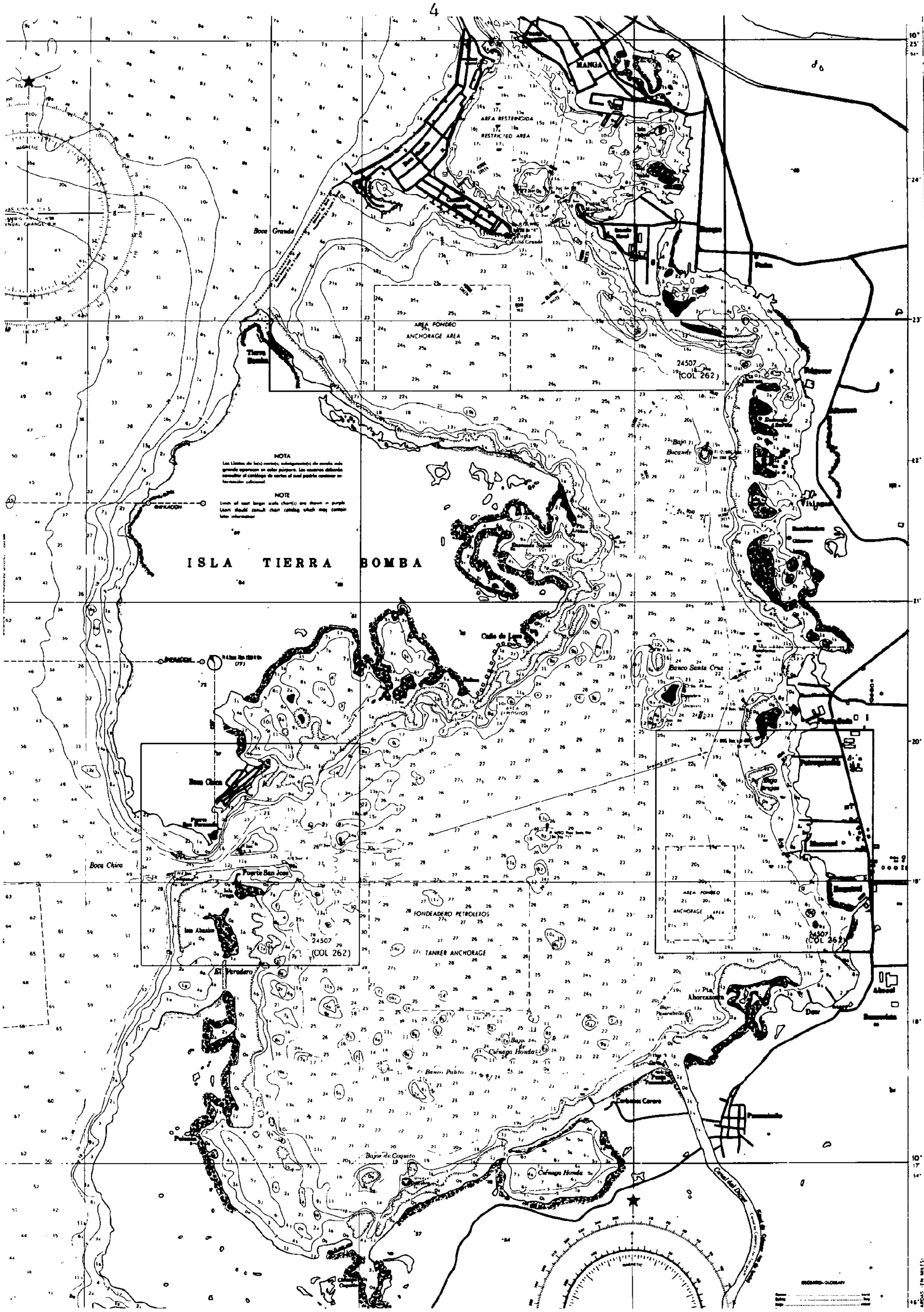



Fig. 2.1. Cartagena Bay. Defense Mapping Agency Chart, COL261. Soundings in m.

embayments, the largest of which forms the inner harbor in the north. The Canal del Dique, which leads water from the river Magdalena in the northwest to the southeastern corner of the Bay was originally dug by the Spaniards to allow boats carrying treasure to reach Cartagena without venturing out into the Caribbean and the waiting pirates. This canal is now a significant source of freshwater and sediment which gives the Bay characteristics similar to those of an estuary.

The extensive urbanization and industrial development have inflicted stresses on the Bay environment. Pollution from domestic and industrial waste is significant but to a large extent not quantified directly. One exception is mercury content, which was found to be at dangerously high levels at least in fishes during an earlier study, FAO/CCO 1978.

In response to the need for better understanding of the present condition of the Bay and to train Colombian professionals in dealing with coastal and estuarine environmental problems the University of Miami with support from International Sea Grant joined together in a cooperative program with the Colombian agencies steered by the Colombian Oceanograhpic Commission (Comision Colombiano de Oceanografia, CCO). UM and CCO would work together in an interdisciplinary effort to carry out a baseline study of the physics, chemistry and biology of the Bay, with training of Colombian personnel being of primary concern.

This report is one of the several resulting from this project and details the hydrodynamic aspects of the problem.

The development of an understanding of the hydrodynamic transport and mixing is an essential phase of the overall effort to formulate a water quality model of the Bay. Such a model is an invaluable tool for developing an understanding of the underlying processes, for data interpretation, and for evaluating the impact of management alternatives for the Bay and its adjacent waters.

While the overall objective of this project is to determine the state of water quality in the Bay, the processes that affect it, and the rates at which changes take place; the specific objective addressed here relates to the hydrodynamic forcing and response of the Bay. Particularly, one would like to determine why, where and how fast a water particle moves (transport and mixing), and what the rate of exchange of water between different areas is(flushing).

## 3. Technology Transfer

As an important part of this project a series of lectures were given to introduce the concepts of coastal hydrodynamics applied to estuaries and bays. These formal lectures were presented in April 1979 to an audience of approximately 50 students of Colombian Universities and navy personnel. The lectures were supplemented by subsequent open discussions of the lecture material.

Through active participation in field measurement exercises and data analysis, further practical training was given to the staff of CIOH (Centro de Investigaciones Oceanograficas e Hydrograficas). This training was amplified by informal lectures on numerical methods and modeling given extemporaneously throughout the duration of the project.

A brief description of the above mentioned activities are now presented.

### 3.1 Short Course

A total of 10 lectures were given in cooperation with the CIOH staff. The lectures presented the rationale for studying coastal hydrodynamics and a qualitative description of the commonly encountered phenomena such as, tides, wind driven currents, dispersion, stratification, data collection, data analysis and modeling. Additional lectures presented the background information on Cartagena Bay and previous work.

As progress was made in the research activities subsequent informal lectures on data analysis, data interpretation, numerical analysis and modeling were presented.

Summaries in Spanish of the formal short course lectures will be given in a separate publication.

3.2 Salinity Computation from Temperature and Conductivity

The CIOH equipment for measuring water mass characteristics consists of a Kahlsico instrument which measures conductivity and temperature from a probe.

Although it is possible to obtain the salinity by using appropriate graphs it is more efficient to computerize the conversion for large quantities of data.

Weyl (1964) derived this empirical formula

$$\begin{aligned}\log K_s &= 0.57627 + 0.892 \log C\ell(^o/oo) \\ &\quad - 10^{-4}\, T\,[88.3 + 0.55\, T + 0.0107\, T^2 \\ &\quad - C\ell(^o/oo)\ (0.145 - 0.002\, T + 0.002T^2)]\end{aligned} \tag{3.1}$$

where $K_s$ = specific conductance in millimhos per cm

$T = 25 - t$

$t$ = temperature in Celcius

The chlorinity $C\ell$ is converted to salinity by the expression, (Cox 1965):

$$S\ ^o/oo = 1.8065\ C\ell\ ^o/oo$$

Equation (3.1) is rearranged

$$\begin{aligned}f(C\ell) &= 8920 \log C\ell\ (^o/oo) + AT\ C\ell\ (^o/oo) \\ &\quad - T[88.3 + 0.55\, T + 0.0107\, T^2] \\ &\quad - 10^4\ [\log K_s - 0.57627] = 0\end{aligned} \tag{3.2}$$

where $A = 0.145 - 0.002\,T + 0.002\,T^2$

This equation (3.2) is solved for $C\ell$ by using a Newton-Raphson iteration. The derivative of (3.2) is

$$f'(C\ell) = 8920\,\frac{1}{\ell n 10}\,\frac{1}{C\ell(^o/oo)} + AT \tag{3.3}$$

The procedure for finding the chlorinity then consists of

1. Obtain initial estimate of $C\ell = K_s/3$
2. Compute $f(C\ell)$ from (3.2)
3. Compute $f'(C\ell)$ from (3.3)
4. Compute new estimate of chlorinity

$$C\ell = C\ell - \frac{f(C\ell)}{f'(C\ell)}$$

The iteration is restarted at step 2 until a sufficiently accurate estimate is achieved usually in less than 10 iterations.

The listing of a FORTRAN program which carries out the above procedure on any standard computer is presented in Appendix A.

### 3.3 Harmonic Analysis

Although small in range the tides may play an important role in the circulation of Cartagena Bay due to their persistence. In order to predict or hindcast the tides at a location, e.g. for the purpose of specifying boundary conditions for a model, it is necessary to have the appropriate tidal harmonic constants.

The technique briefly reviewed here for obtaining the harmonic constants from a measured time series is described in more detail by Dronkers (1964).

Let the measured time series be given by y(n), n = 1, 2 ... N. The predictor to be used is

$$z(n) = A_o + \sum_{i=1}^{I} \{A_i \cos (\frac{2\pi}{T_i} n \Delta t) + B_i \sin (\frac{2\pi}{T_i} n \Delta t)\}$$

where $\Delta t$ is the sampling interval and $T_i$ are the astronomical tide periods for which the harmonic constants, $A_i$ and $B_i$, are desired.

The harmonic constants are determined using the least squares method such that

$$E = \sum_{n=1}^{N} (y(u) - z(u))^2$$

is minimized. This is achieved when

$$\frac{\partial E}{\partial A_i} = \frac{\partial E}{\partial B_i} = 0 \qquad \text{for} \quad i = 0, 1, \ldots I$$

These 2I+1 equations are solved simultaneously for the A's and B's.

The FORTRAN listing of a program that performs a least squares harmonic analysis is contained in Appendix B.

## 3.4 Modeling

The use of models is essential for the analysis of circulation in a complicated water body such as Cartagena Bay. The models can be a significant aid in interpreting field measurements and are invaluable tools for predicting purposes.

A set of numerical finite element models are available and could be adapted to the Bay. These include a 2-D vertically integrated hydrodynamic model Wang (1978), a two layer 2-D vertically integrated hydrodynamic model Wang (1975) and a 2-D vertically integrated dispersion model

Leimkuhler et. al. (1975).

The transfer of these models to the staff of CIOH was hampered by lack of a suitable computer at the Naval Academy and also disrupted by the transfer of personnel since the people with a background in oceanography usually are career officers.

Nevertheless a number of informal lectures were presented to Tn. Medina, Tn. Urbano and Mr. Pagliardini of CIOH. These lectures covered numerical techniques, mainly finite difference methods, and the formulation of hydrodynamic model equations.

In September 1981 Tn. Medina spent one week in Miami learning to use the two-layer model for Cartagena Bay and to produce a user's manual.

## 4. Data Collection

Information on a number of parameters governing the flow or delineating the flow response in Cartagena Bay was collected.

In order to include seasonal effects an attempt was made to carry out the field work on a quarterly basis and over a duration of 2 years so that the repeatability of observations also could be established. The first sampling period took place in June and July of 1979 and the last in May of 1981. After initial coordination and supervision the field effort was carried out by CIOH staff and copies of the raw data transmitted to University of Miami for further analysis.

### 4.1 Canal del Dique

This man-made canal which connects the River Magdalena with Cartagena Bay plays several important roles in the water quality of the Bay. It is the major source of freshwater and probably also of non-marine sediment to the Bay.

Due to very shallow depth (1 to 2 m) at places only minimal boat traffic takes place in the lower most reach of the canal, consideration is being given to deepen the canal for deeper draft vessels.

The discharge in the canal is primarily governed by the rainfall in the River Magdalena's catchment areas. The discharge rates for the years 1975-1978 as inferred from measured stages are shown in Fig. 4.1. It is estimated that approximately 1/5 of the flow at Incora reaches the Bay. No records are available after 1978.

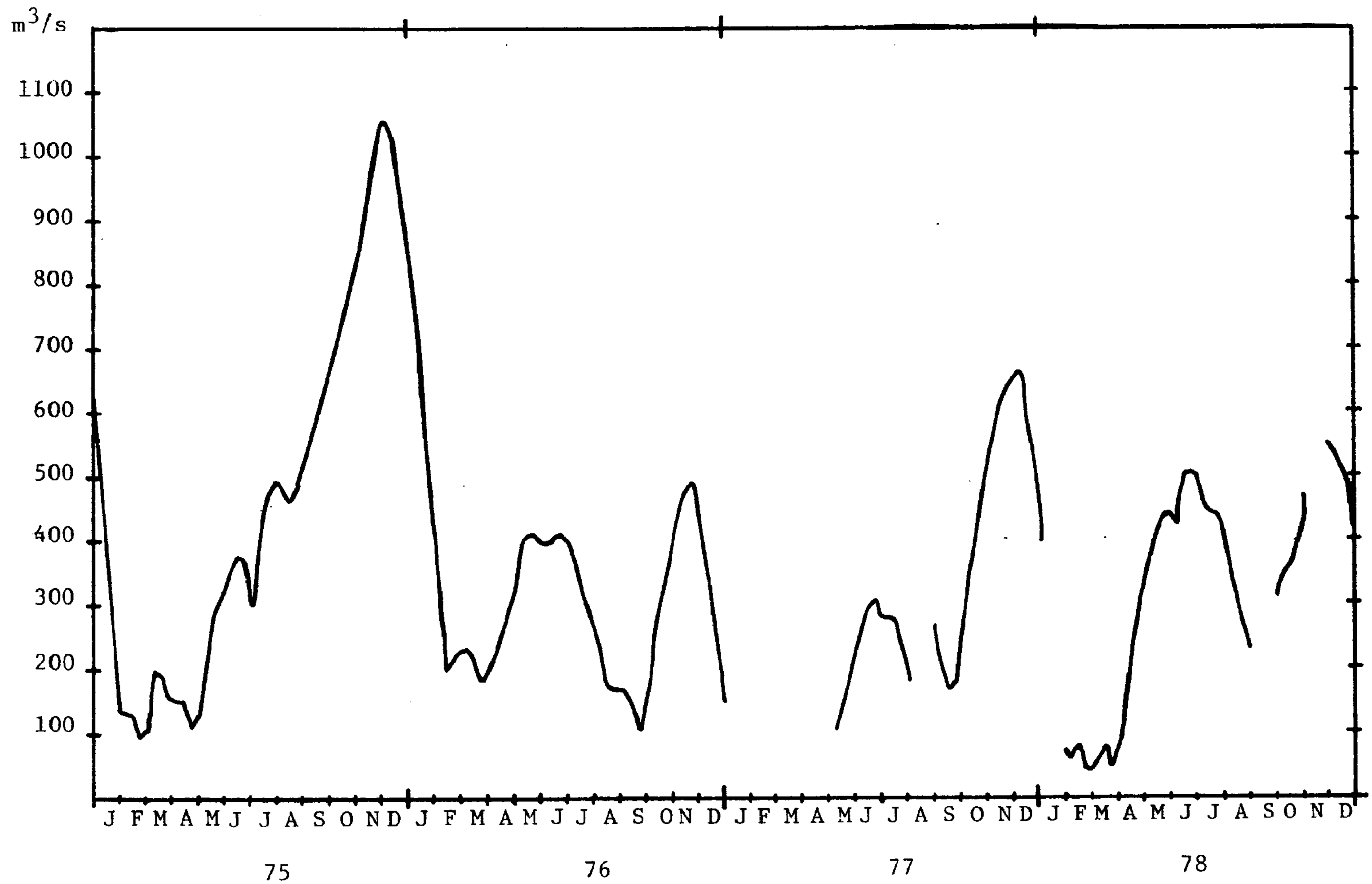



Figure 4.1. Canal del Dique discharge at Incora, Km 7. 1975-78

Along with the canal fresh water a large amount of sediment is brought into the Bay. The transport rates vary with flow rate but may reach close to 3000 kg/s during peak periods. About 22000 $m^3$/year of sediment enters the Bay as bed load and it is estimated that the total load is approximately 330000 $m^3$/year. If all the sediment was spread evenly over the bottom this would roughly correspond to an accumulation of 4 mm/year. In reality an unknown quantity of sediment is probably exported from the Bay to the adjacent ocean.

## 4.2 Rainfall

The average monthly rainfall measured over 31 years at Crespo airport, Cartagena and over 14 years at El Banco, Magdalena provins are shown in Fig. 4.2.

## 4.3 Wind

The winds in the area show a distinct seasonal pattern with a strong sustained wind out of the north during winter and lighter more variable winds generally out of the south-southwest the rest of the year. Some sea breeze effect is also noticeable.

## 4.4 Tides

Tidal elevations were recorded at Isla Tierra Bomba near Boca Grande and at the pilot house dock at Fort San Jose near Boca Chica. The tide gauges were Stevens Type F water level recorders. This gauge operates on the float system and records the elevations on a graph paper.

Attempts were made to measure tidal elevations at the two stations simultaneously and over a month long duration. However, due to various

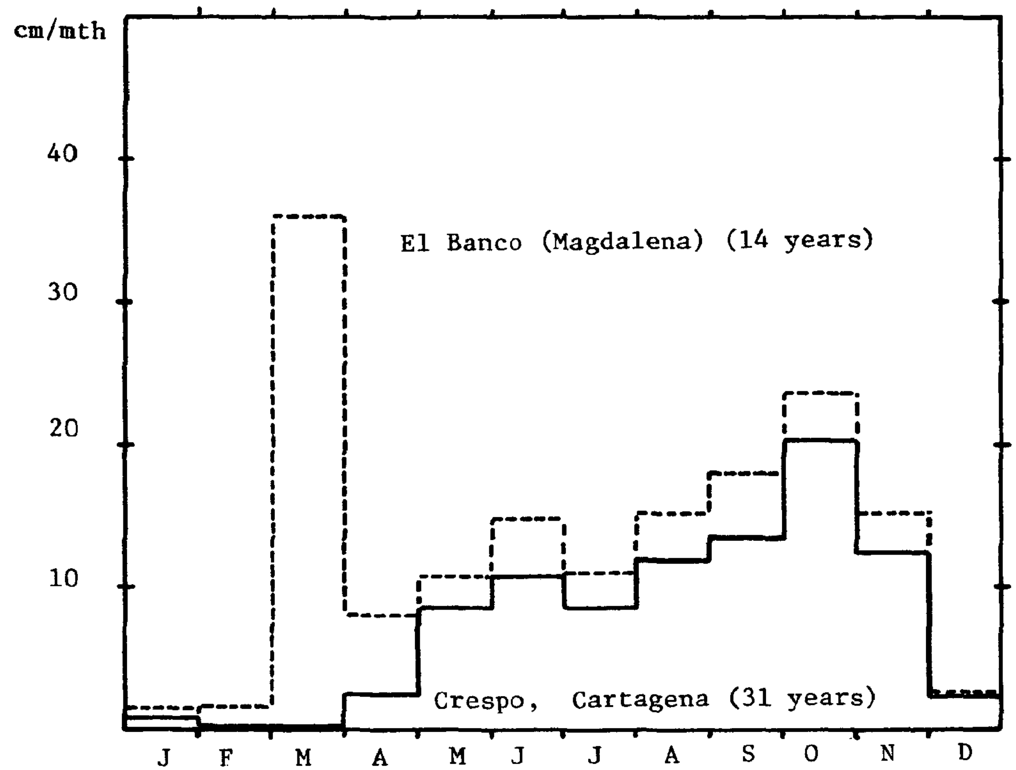



*Figure* 4.2. *Average monthly rainfall* malfunctions this was not possible.

Useful data were obtained from the Boca Grande gauge for the period 09:00, July 22, 1980 to 21:00 August 19, 1980.

The Boca Chica gauge produced data from 10:30 September 16, 1980 to 10:30 October 13, 1980.

Figures 4.3 and 4.4 show plots of parts of the data. Unfortunately, no overlap was obtained during this period. Short periods of overlapping data were obtained during October 1980. The longest uninterrupted period is shown in Fig. 4.5.

Attempts to obtain tidal data from the Bay interior were unsuccessful because of difficulties with gauge operation and servicing. The mean tide range in the Bay is about 20 cm, while the mean diurnal range is 33 cm.

4.5 Salinity-Temperature-Depth Profile

Profiles of conductivity salinity and temperature were measured against depth on a quarterly basis. A Beckman RS5-3 portable instrument and a Kahlsico instrument were used. Although, the Beckman is a far superior instrument which gives direct salinity readout the Kahlsico had to be used when the Beckman was unavailable.

Due to the small tidal range and motion it was found that profiles taken during high water slack and low water slack were undistinguishable. Each sampling period covered the 12 stations shown in Fig. 4.6.

The raw data are tabulated in Appendix C and plotted in Figs. 4.7a to 4.7g. Due to lack of proper calibration or instrument inaccuracy several

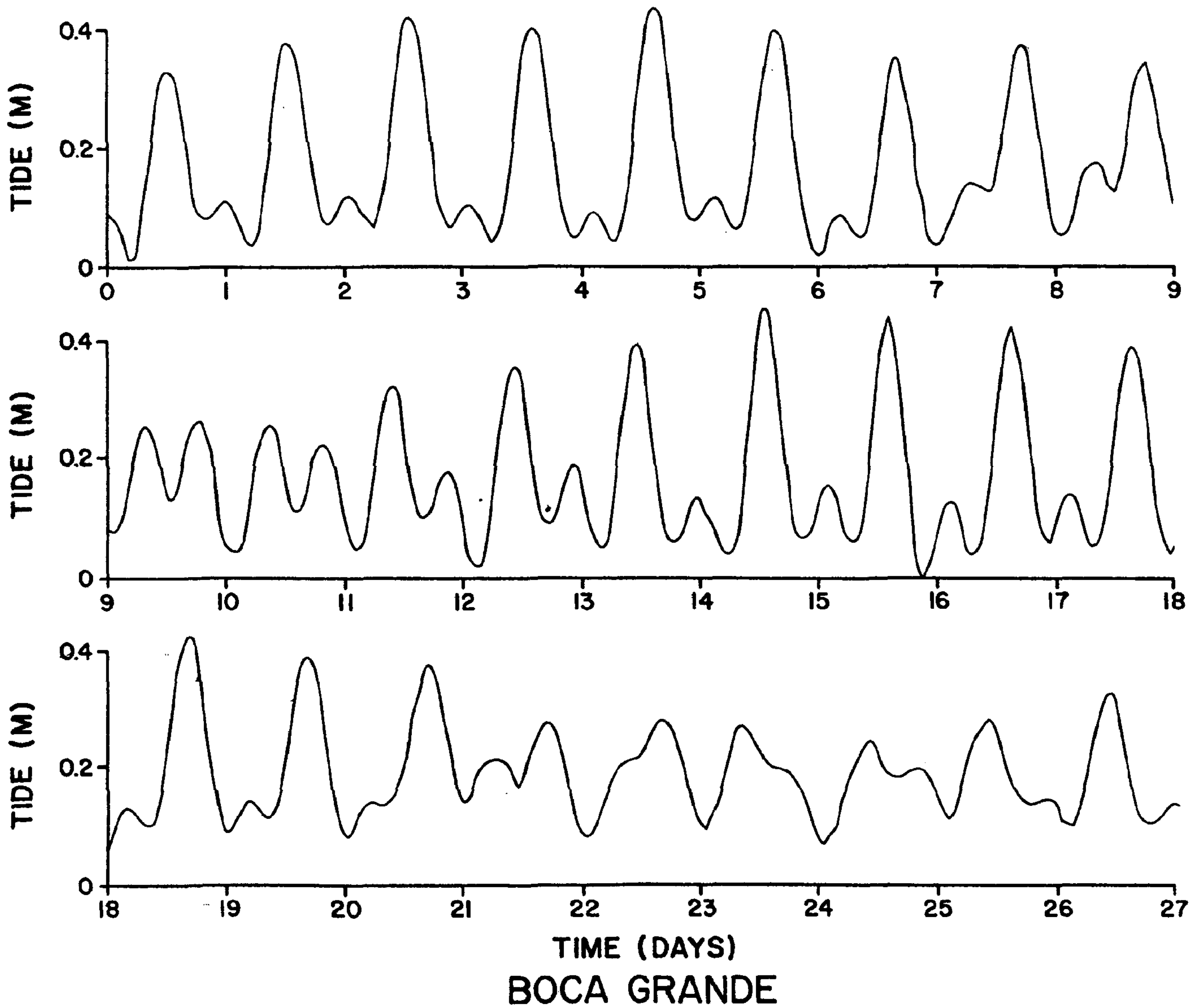



Fig. 4.3. Boca Grande tides, record begins July 22, 1980 at 09:00 Hrs.

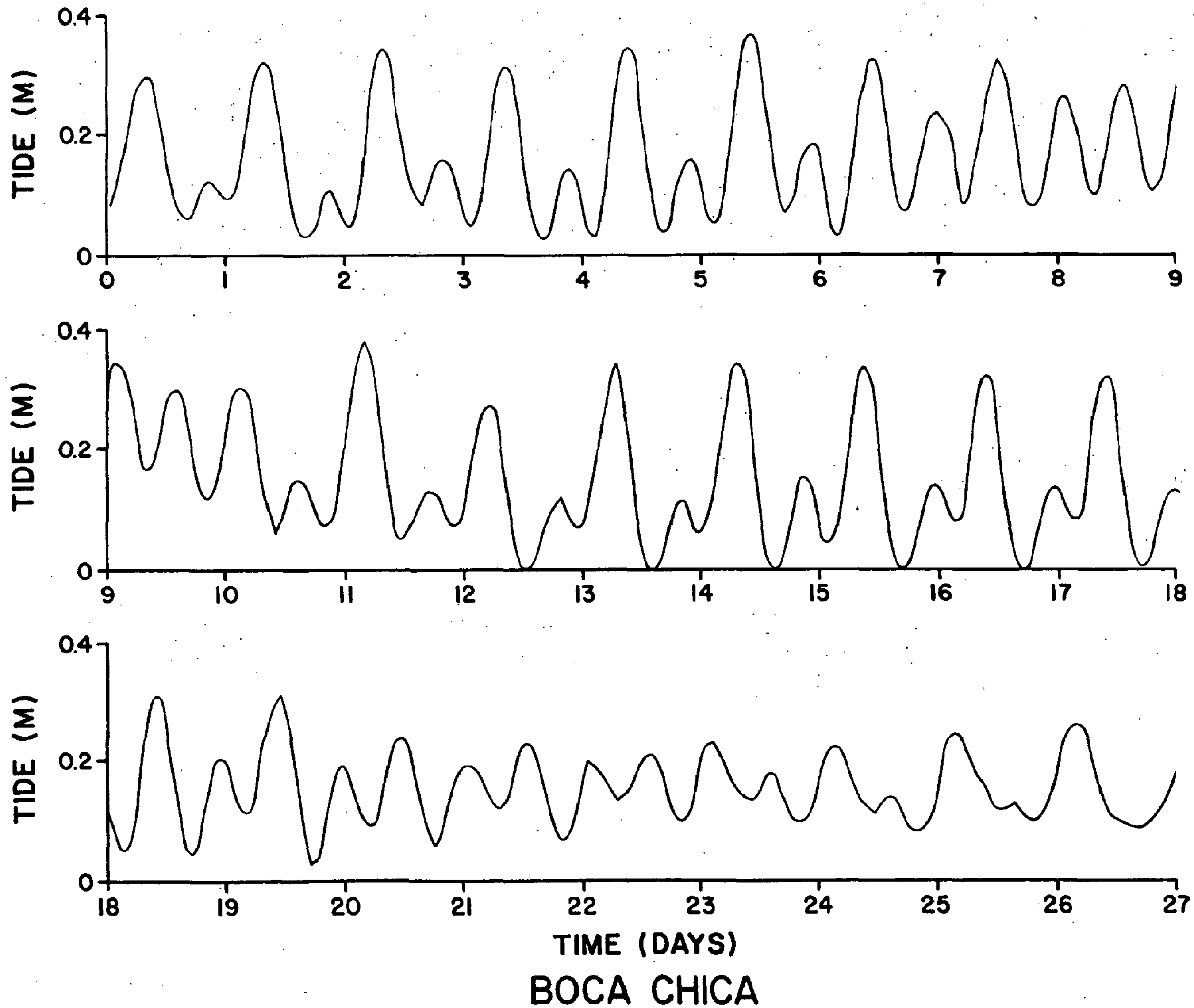



Fig. 4.4. Boca Chica tides. Record begins September 16, 1980 at 10:30 hrs.

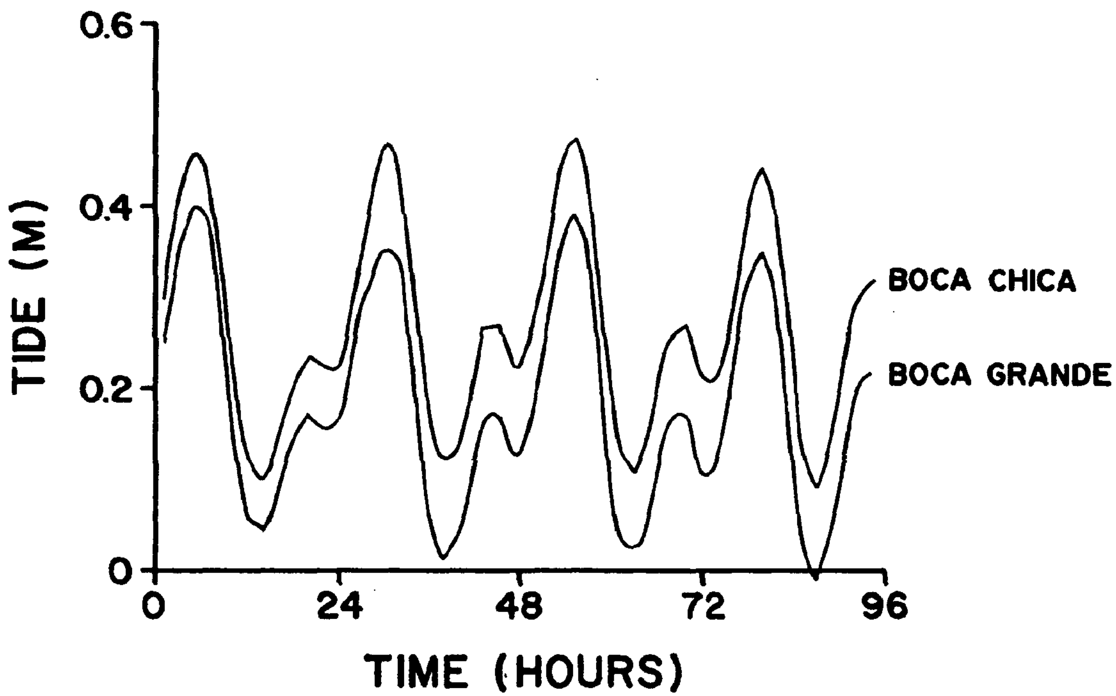



Fig. 4.5. Simultaneous tidal elevations at Boca Grande and Boca Chica.

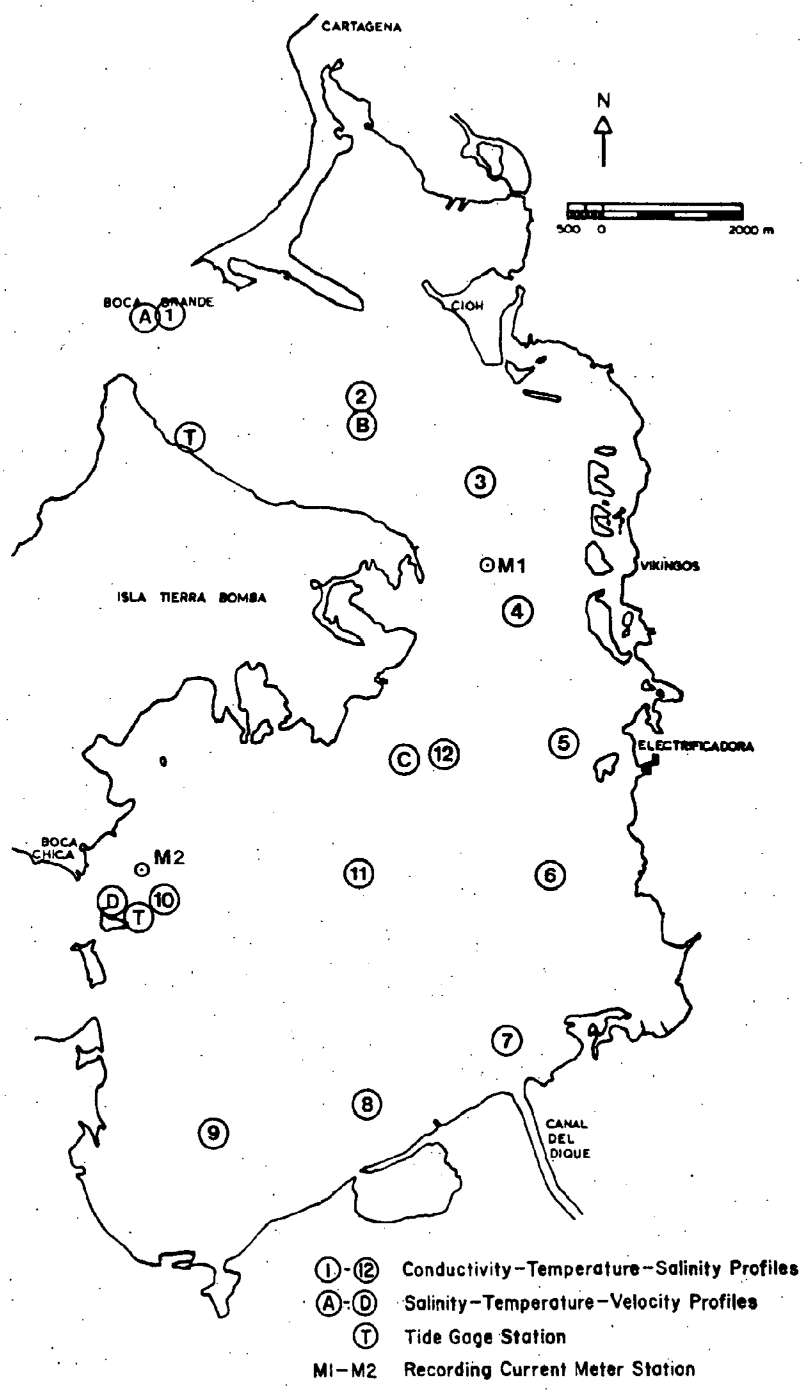



Fig. 4.6. Hydrographic sampling stations in Cartagena Bay

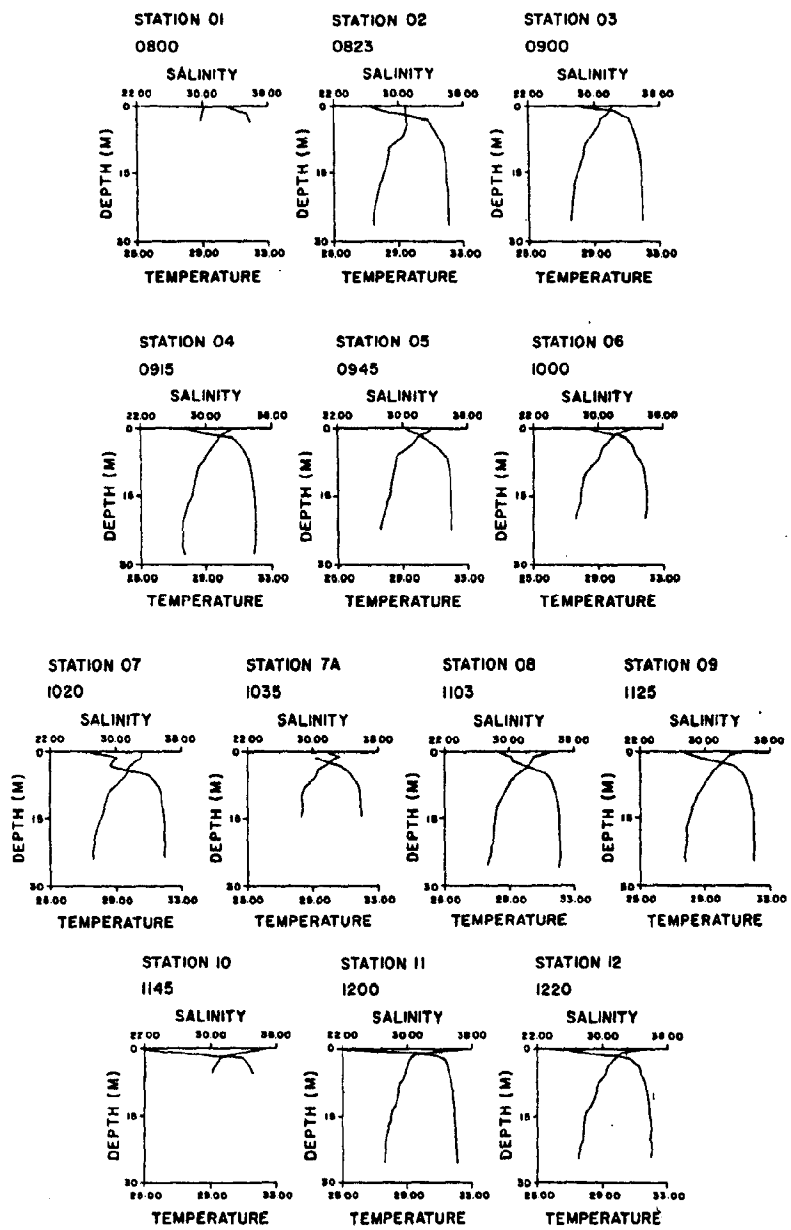



Fig. 4.7a. Salinity-temperature graphs. June 21, 1979

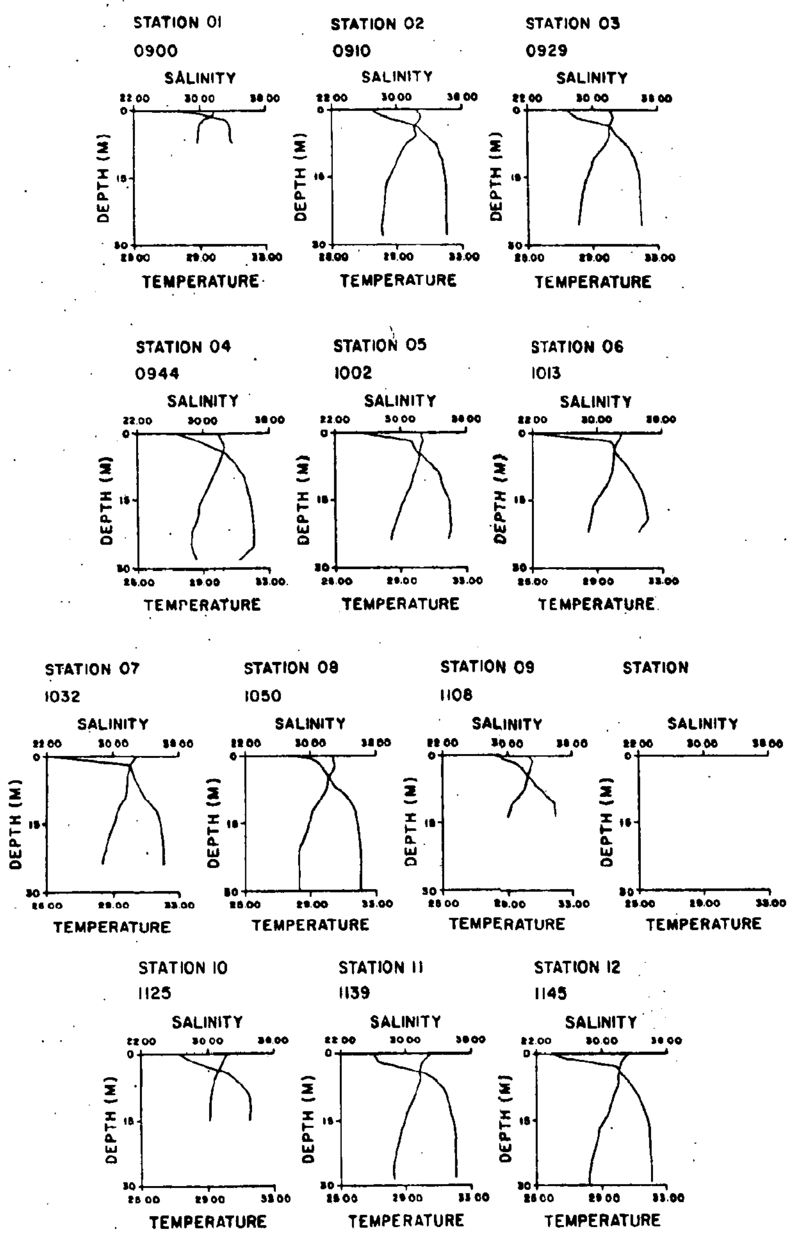



Fig. 4.7b. Salinity-temperature graphs. October 16, 1979.

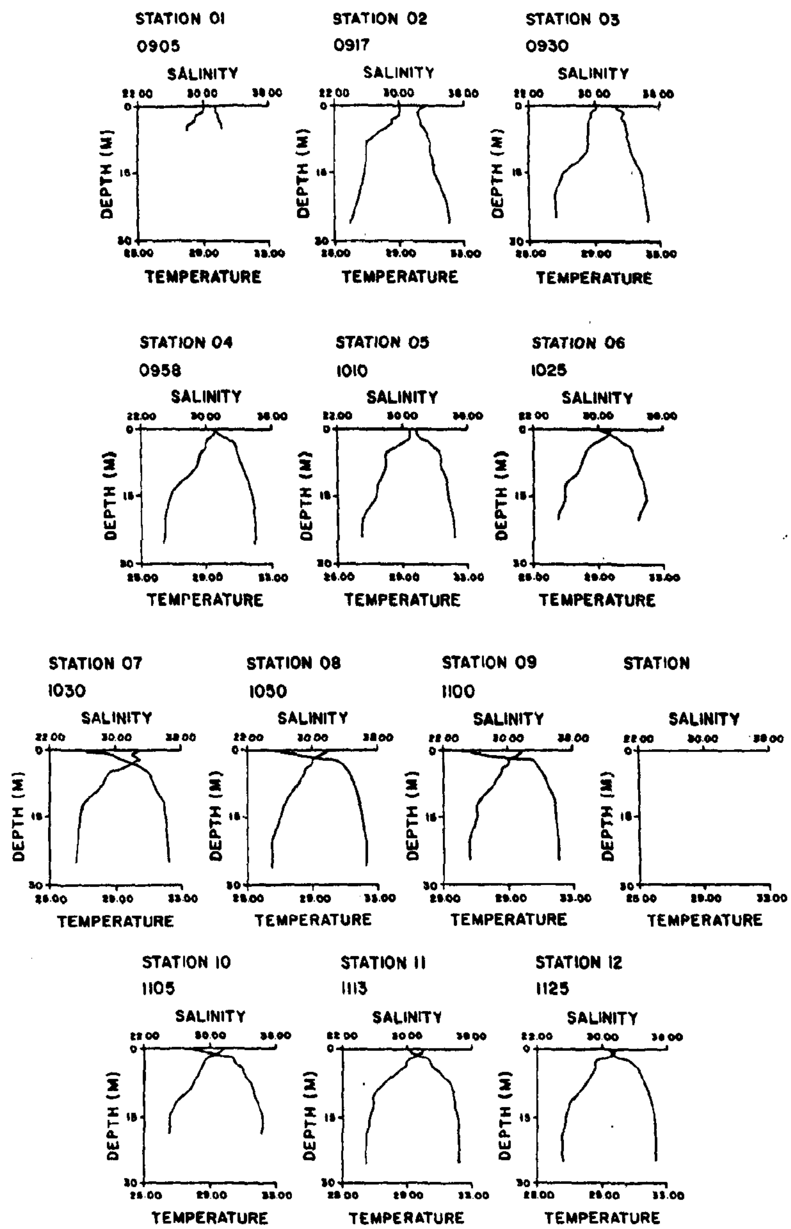



Fig. 4.7c. Salinity-temperature graphs. May 5, 1980.

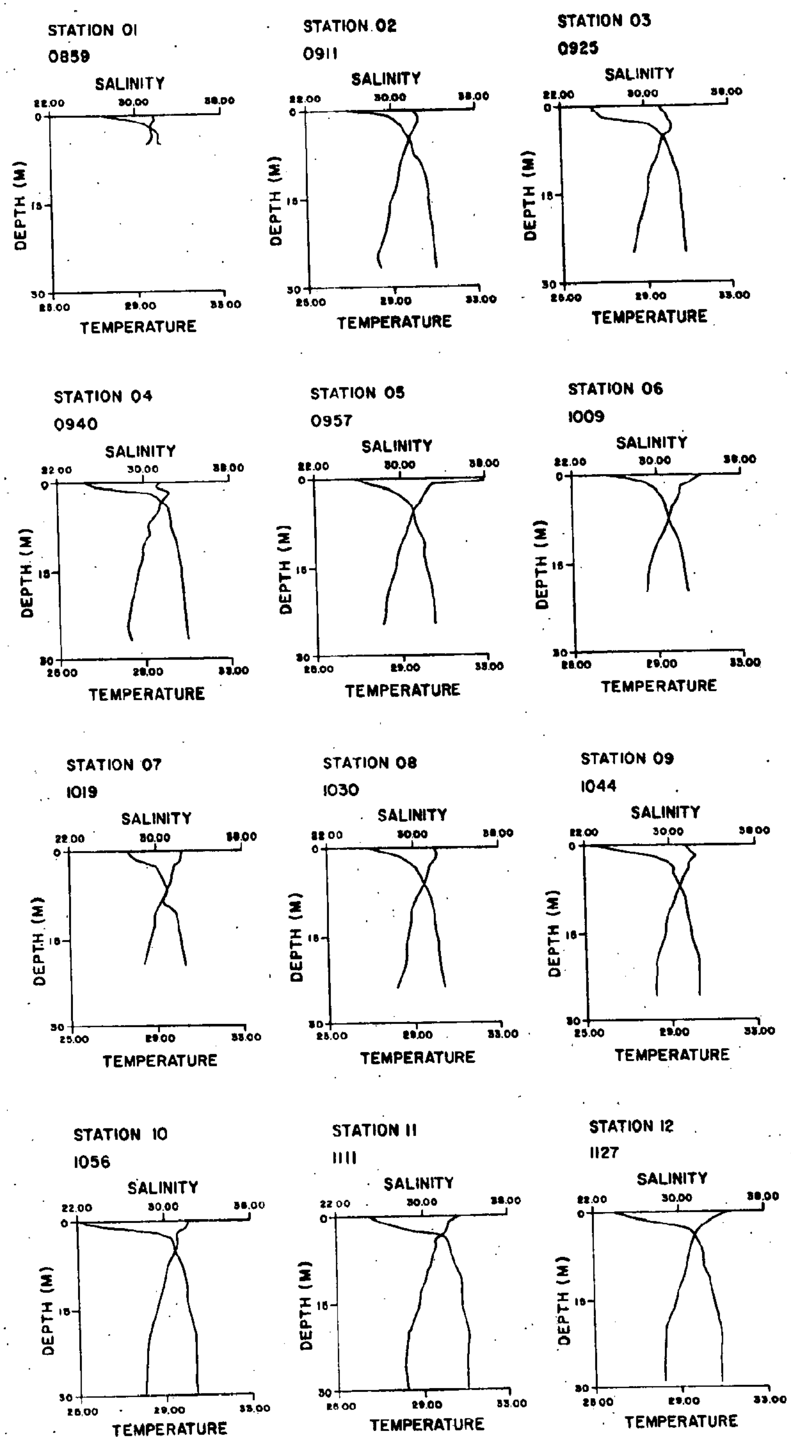



Fig. 4.7d. Salinity-temperature graphs. October 28, 1980.

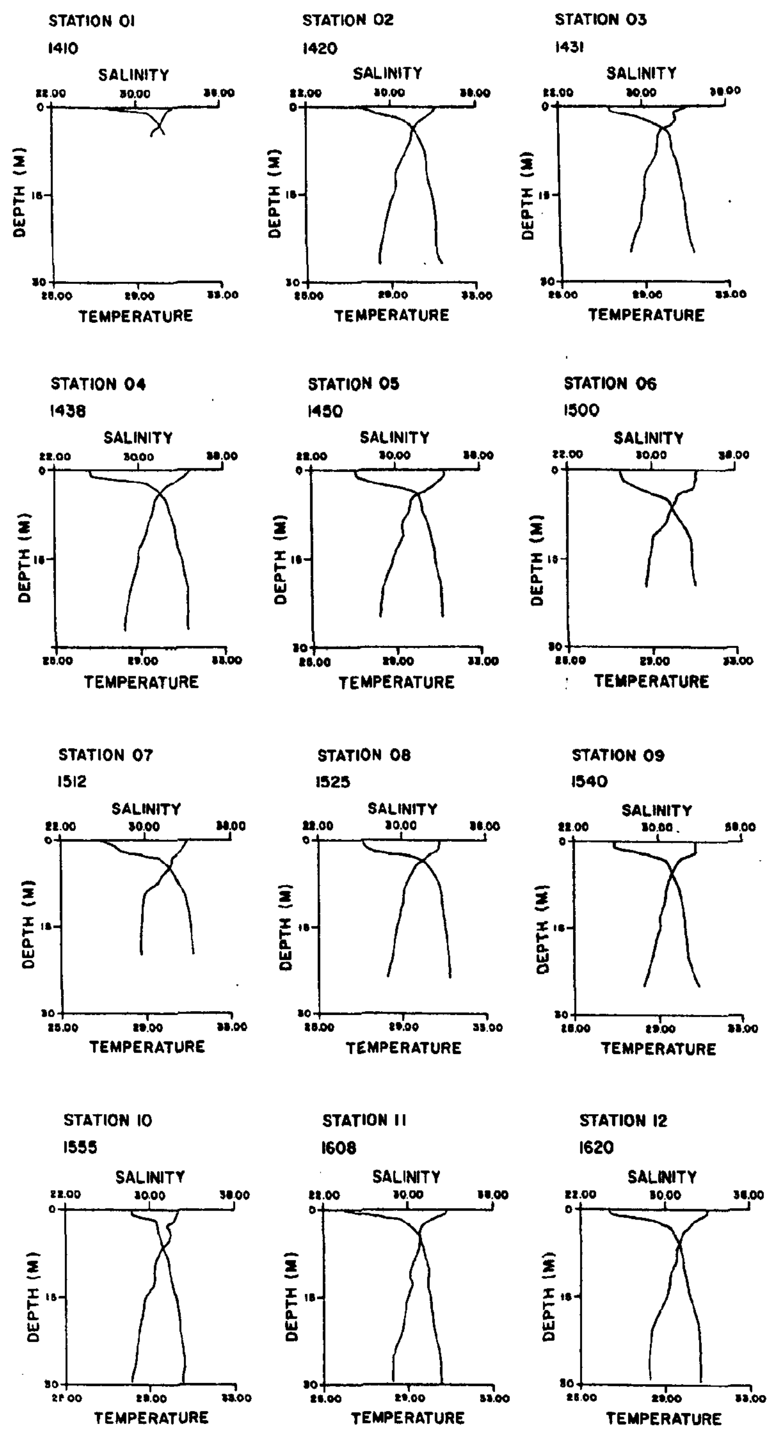



Fig. 4.7e. Salinity-temperature graphs. October 28, 1980.

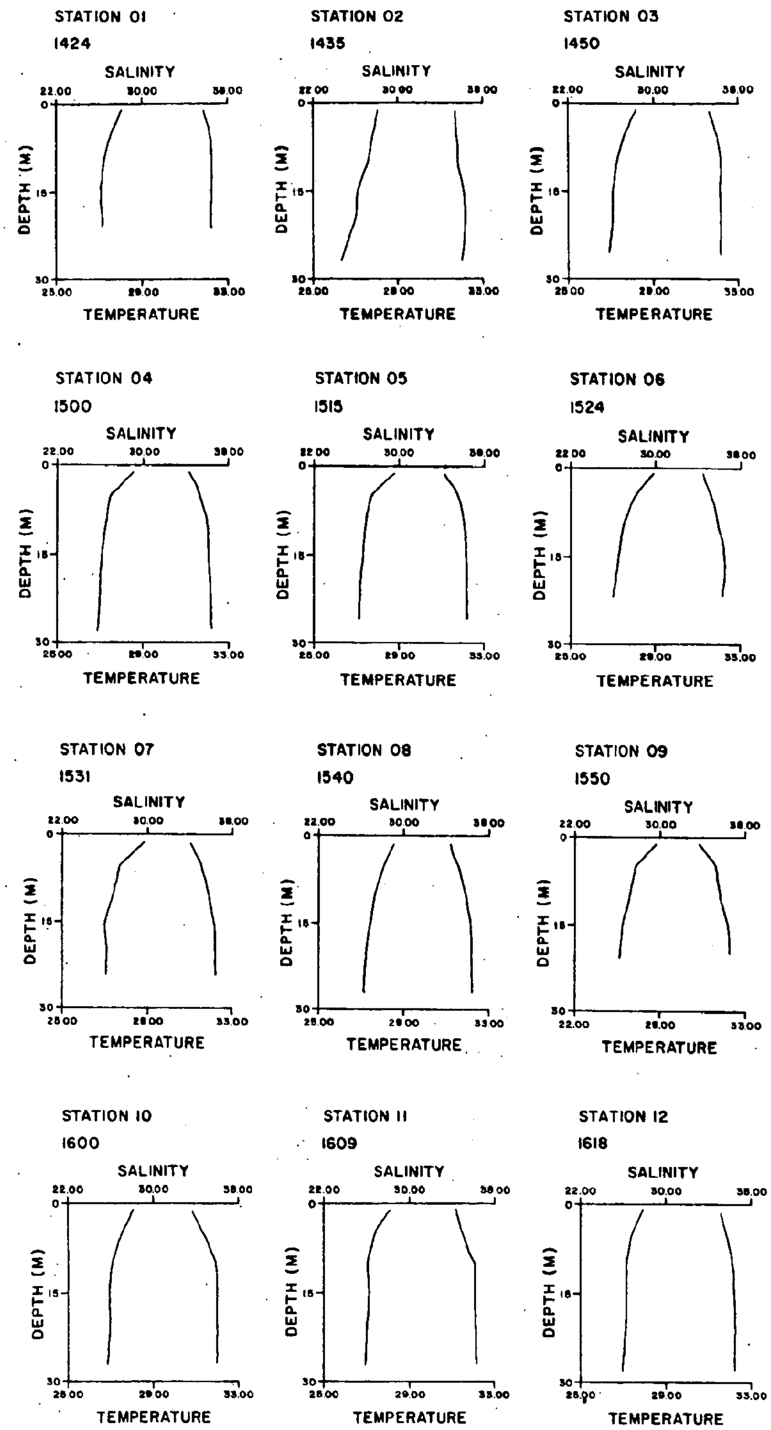



Fig. 4.7f. Salinity-temperature graphs. February 9, 1981.

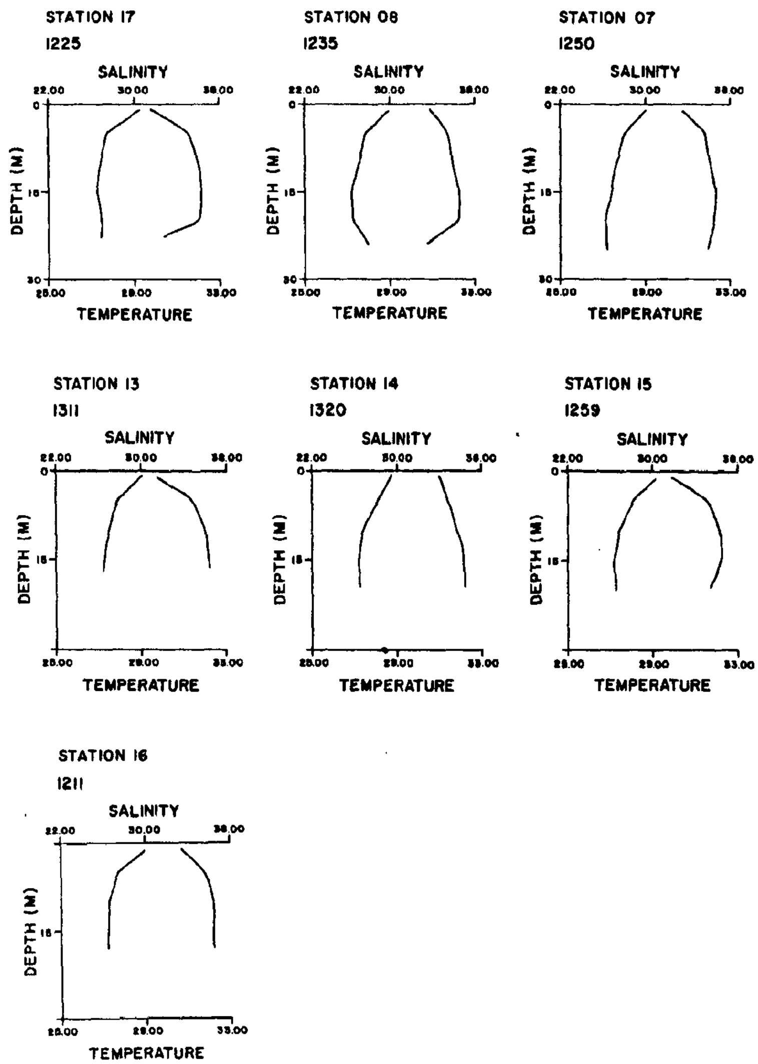



Fig. 4.7g. Salinity-temperature graphs. February 10, 1981.

readings of salinity were 37‰ or above. Since laboratory analysis of water samples taken for the chemical analysis did not show such high value the plotted data are corrected to yield similar maximum salinity values. The correction was made by making the maximum salinity in a profile equal to the maximum value found in the laboratory and subtracting the difference from each of the values in that profile. The absolute value for salinity in a profile is therefore subject to some inaccuracy, however the relative variation of values within the profile should be reasonably accurate.

### 4.6 Drogues

A number of drogue studies were carried out in June and July 1979. One study consisted of the deployment and tracking of three drogues placed at different depths. The drogues were made by joining two square pieces of plywood at a right angle to form a cross. Weighted and tied with a string to a surface buoy the drogue is assumed to follow the path of the surrounding water particles.

Tracking of the drogues was accomplished by shooting sextant angle from a boat to fix points on land. The observed drogue paths are shown in Fig. 4.8. Since considerable inaccuracy is inherent in this positioning system the relative drogue motion is more significant than the absolute motion. The wind during the measurements is listed in Table 4.1.

The drogue experiments were carried out under the charge of Ricardo Parra Suarez of CIOH.

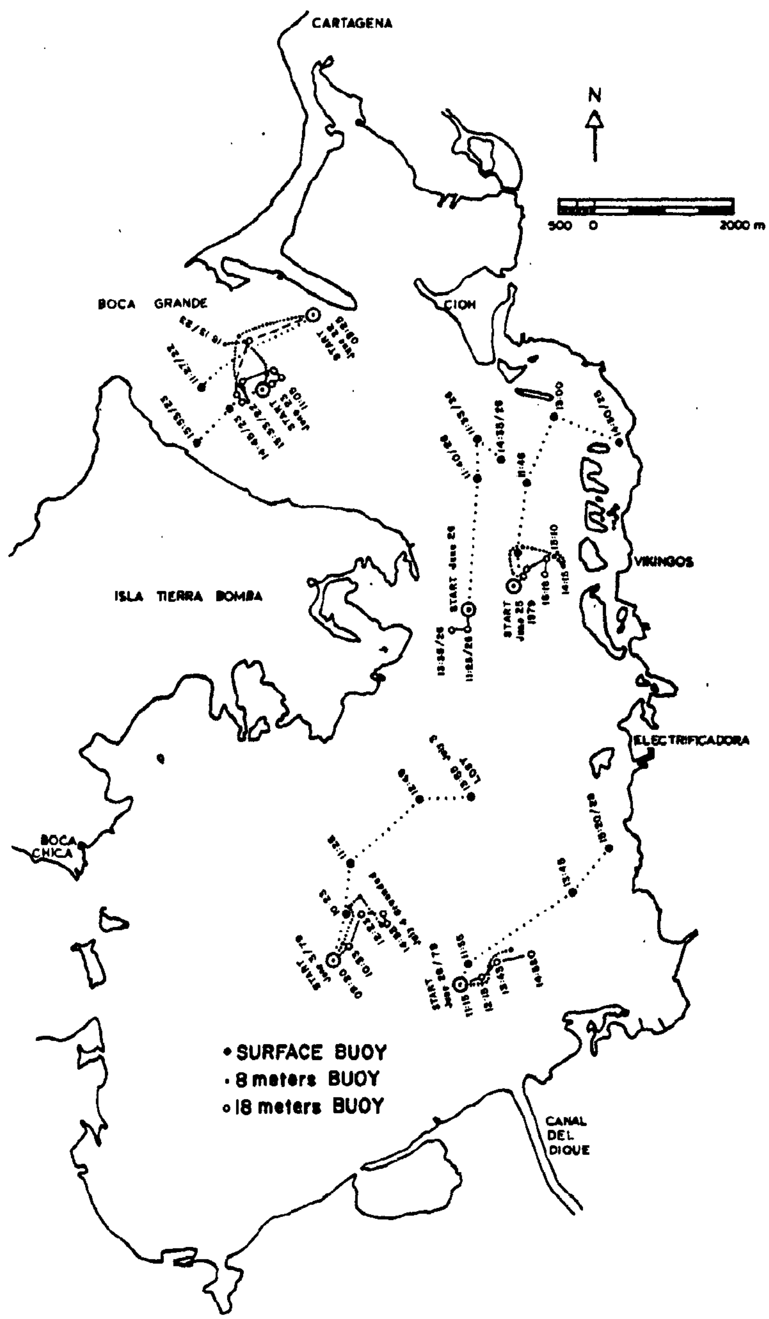



Fig. 4.8. Observed drogue paths.

| Date | Time | Wind | |
|---|---|---|---|
| | | Direction | Speed km/hr |
| June 22 | 0900 | SW | 5 |
| | 10:20 | SW | 7.5 |
| | 11:15 | SW | 6 |
| | 14:10 | SW | 8 |
| | 15:06 | SW | 9 |
| | 15:33 | NW | 8 |
| | 16:00 | NW | 10 |
| 23 | 10:00 | Calm | |
| | 11:05 | SW | 10 |
| | 12:10 | SW | 10 |
| | 13:11 | SW | 12 |
| | 14:45 | Calm | |
| | 15:53 | N | 10 |
| 25 | 10:30 | Calm | |
| | 10:55 | Calm | |
| | 12:00 | Calm | |
| | 13:20 | NW | 10 |
| | 14:15 | NW | 10 |
| | 15:35 | NW | 10 |
| 26 | 09:20 | Calm | |
| | 10:00 | Calm | |
| | 11:00 | SE | 3 |
| | 11:45 | Calm | |
| | 12:00 | NW | 8 |
| | 14:35 | NW | 10 |
| 28 | 11:15 | W | 7 |
| | 13:45 | W | 7 |
| | 15:00 | W | 6 |
| | 15:20 | W | 6 |

| Date | Time | Wind | |
|---|---|---|---|
| | | Direction | Speed km/hr |
| July 3 | 09:00 | Calm | |
| | 10:00 | W | 3 |
| | 10:30 | S | 3 |
| | 11:00 | Calm | |
| | 12:30 | SW | 7 |
| | 12:45 | NW | 3 |
| | 13:00 | NW | 10 |
| | 15:00 | Calm | |
| 4 | 11:07 | SW | 10 |
| | 12:42 | SW | 5 |

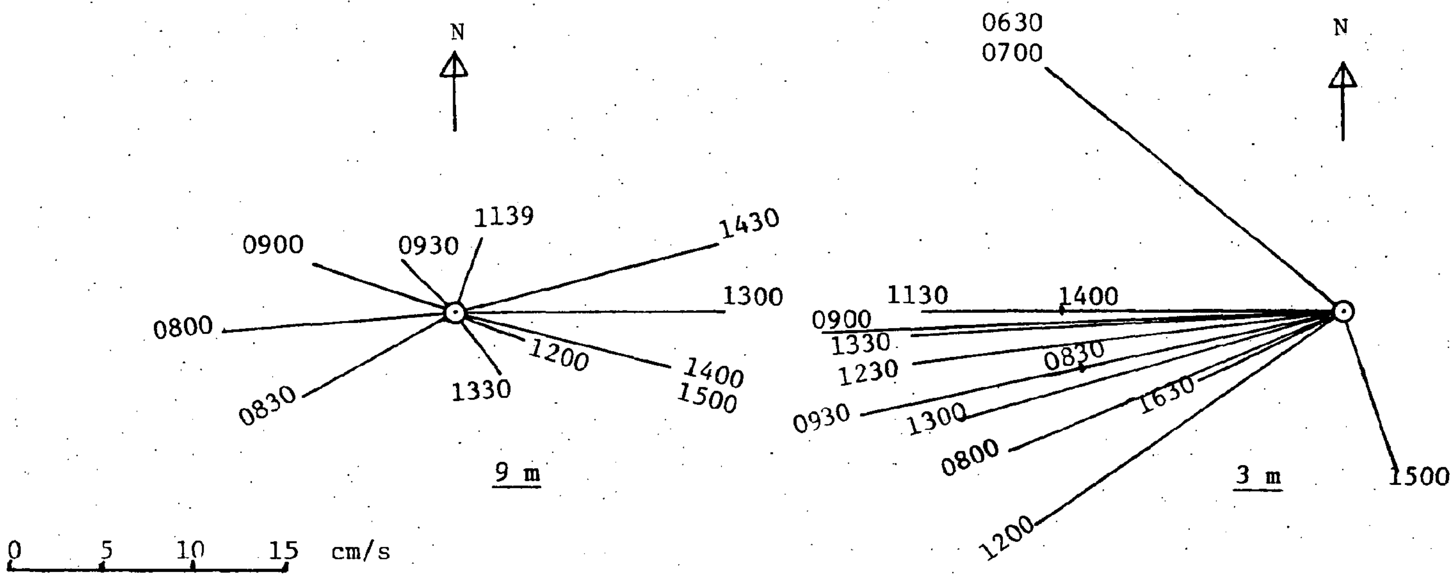
Table 4.1. Wind speed and direction during drogue experiments.

4.7 Currents

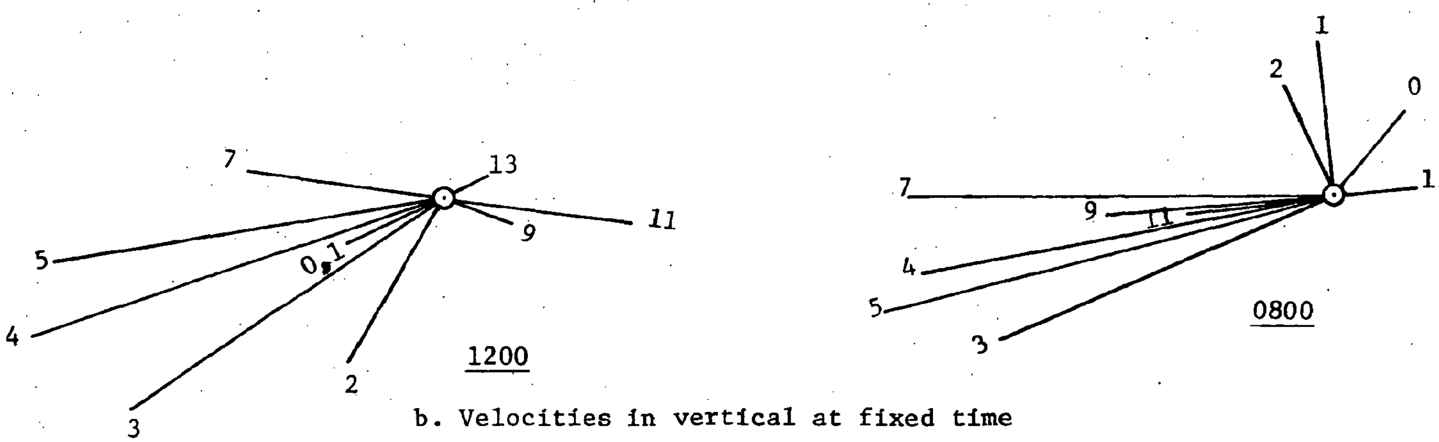
Current velocities were measured at a number of locations shown in Fig. 4.6. Two modes of operation were employed. One consisted of using a portable electromagnetic current meter (Marsh-McBirney) from an anchored boat. The direct read out feature of this system is an advantage. Also, the ability to carry out vertical profiling and to choose sampling stations irrespective of ship traffic is of importance. The major drawback of using this mode of operation are the relatively short continuous sampling periods and the susceptibility to interference by surface gravity waves that rock the boat. This latter effect, in fact, made it impossible to obtain good data at Boca Grande since waves always seem to be significantly present there.

Figure 4.9 shows the measured velocities at Boca Chica, D of Fig. 4.6, and Fig. 4.10 shows velocities near Caño de Loro, C of Fig. 4.6.

In a second mode of operation a moored recording current meter was used to obtain a longer time record less subjected to interference from surface waves. The current meter used is a Sea Trak Savonius rotor instrument produced by Hydroproducts. It was installed in the narrowest section of the Bay in front of Punta Arenas using a taut mooring system with a subsurface buoy, see Fig. 4.6. The meter was first placed at approximately 20 m below MSL for 14 days, then moved to 4 m below surface for another 28 days and finally back down to 20 m. During this latter installation an Inter-Ocean current meter was placed simultaneously at 4 m. Unfortunately, the Inter-Ocean system never recorded any useful data.




a Velocities in time at fixed depth




b. Velocities in vertical at fixed time

FIG. 4.9. Velocity plots (hydrographs) at Boca Chica. October 18, 1979.

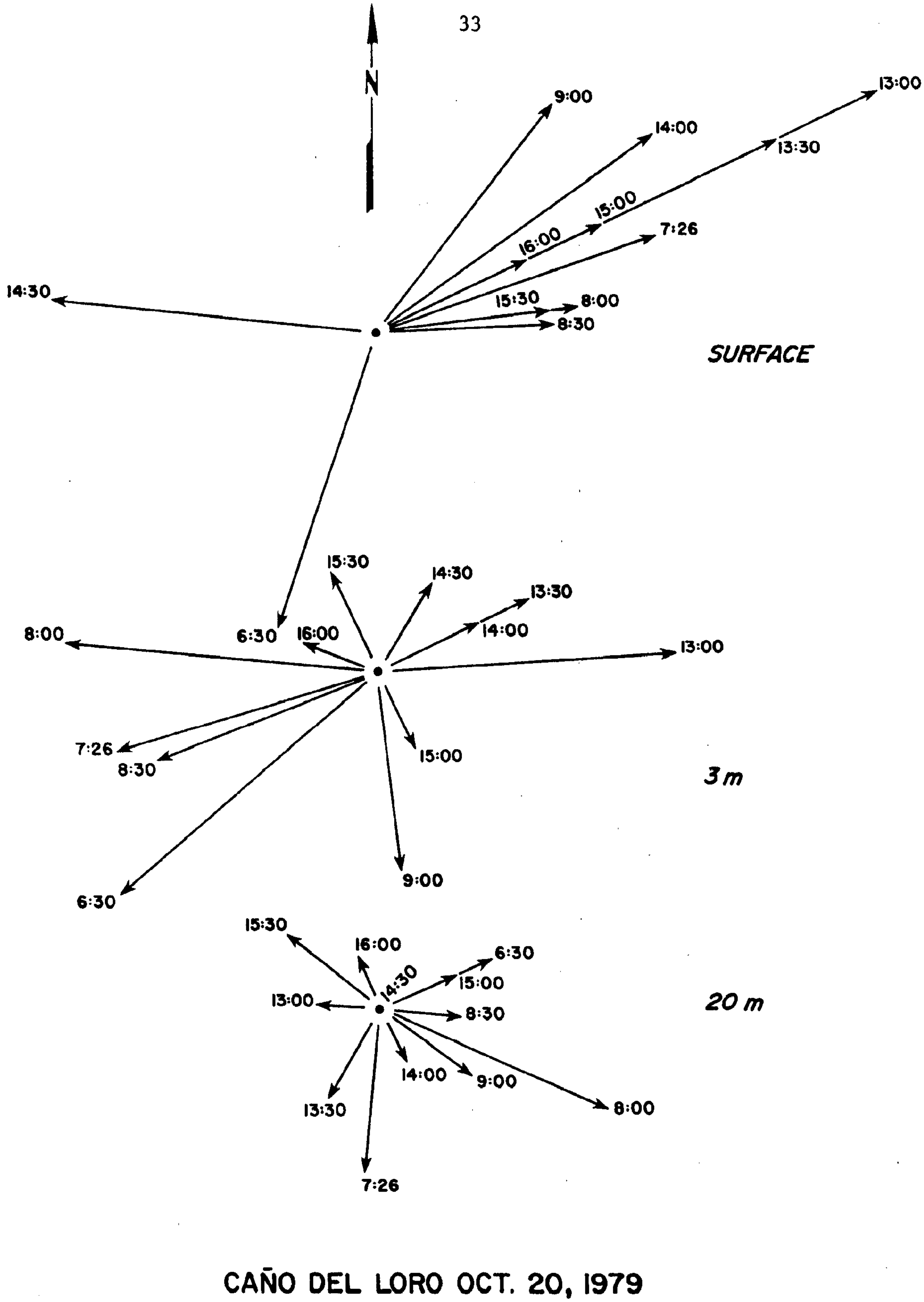



Fig. 4.10. Measured Velocities.

In the first deployment at 20 m depth, the Sea Trak current meter malfunctioned and no velocities were recorded. However, the following deployments were apparently more successful providing more than 20 days of data at 4 m depth starting June 4, 1981, Fig. 4.11, 15 days of data at 20m depth starting July 8, 1981, Fig. 4.12 and about 2 days of data at 20 m depth near Boca Chica starting July 23, 1981. At Boca Chica the current meter stopped working on the third day. The conductivity and pressure monitoring systems were malfunctioning during all the observations.

It was intended that during the deployment of the recording meter weekly profiles would be taken with the portable current meter and S.T.D. meter in order to compare the measurements and to develop a picture of the vertical structure. These profiles were not made.

## 4.8 Turbidity

The turbidity of water samples collected at approximately 40 chemistry stations were determined using a laboratory nephelometer made by Hach. The measurements were carried out for July and October 1980, and January and May 1981. The results obtained from surface and bottom samples are shown in Figs. 4.13 a-h.

The measurements were done mainly to provide a qualitative picture of the turbidity distribution and possible sink or source areas. Hence, no attempts were made to relate turbidity units with actual contents of solids.

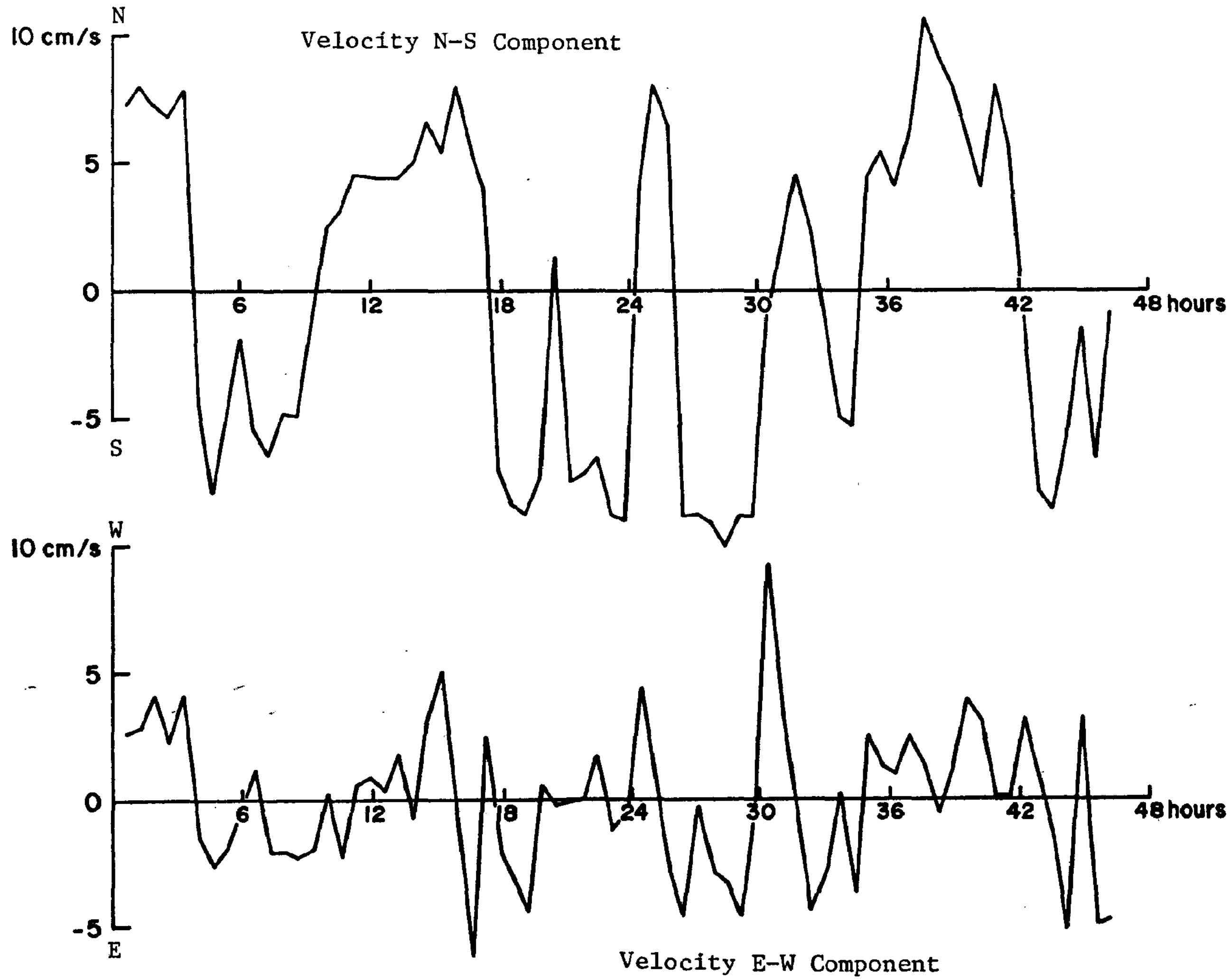



Fig. 4.11. Measured velocities at Punta Arenas. June 1981.

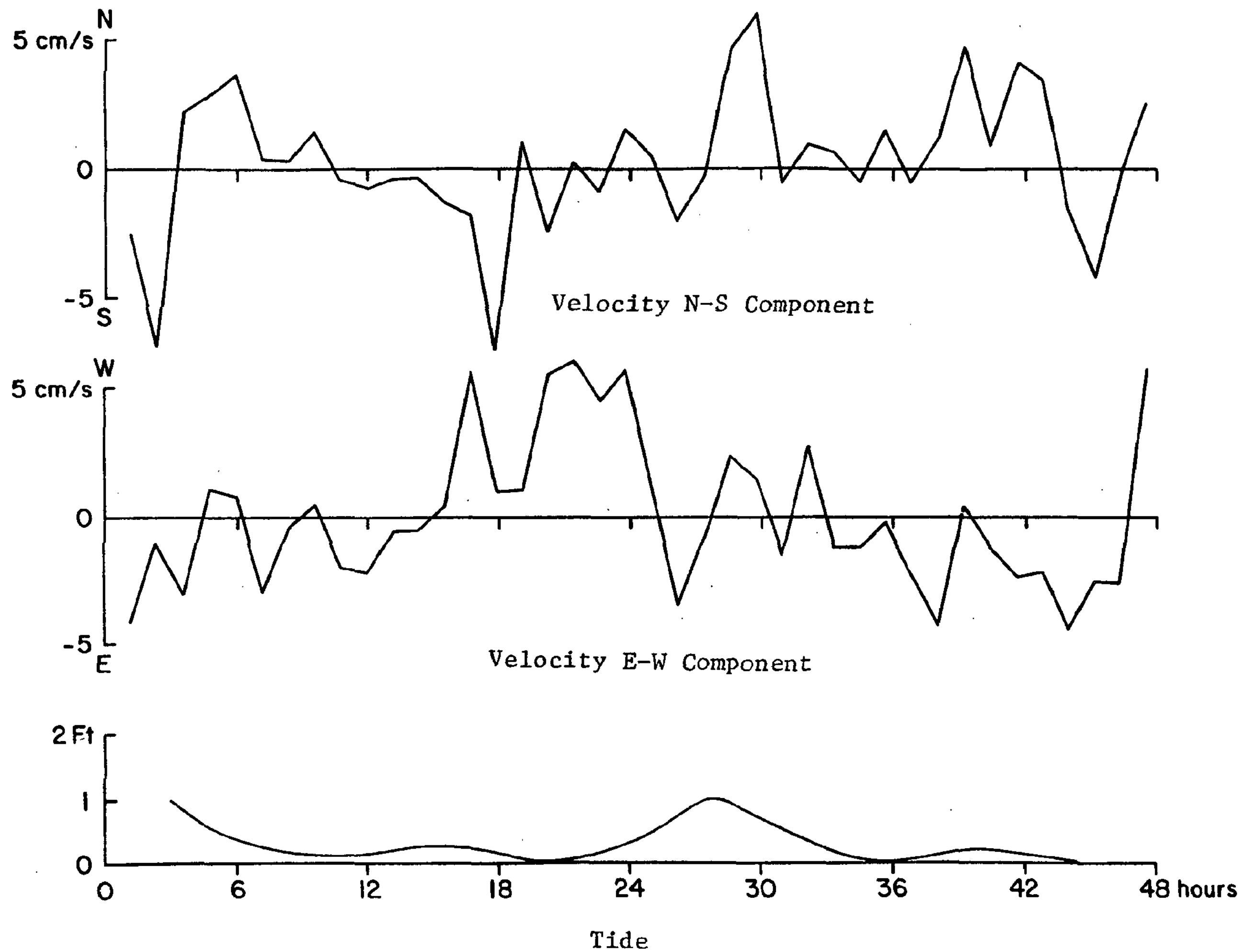



Fig. 4.12. Measured velocities at Punta Arenas. 20 m below surface. July 1981. The predicted tide at Cartagena is also shown.

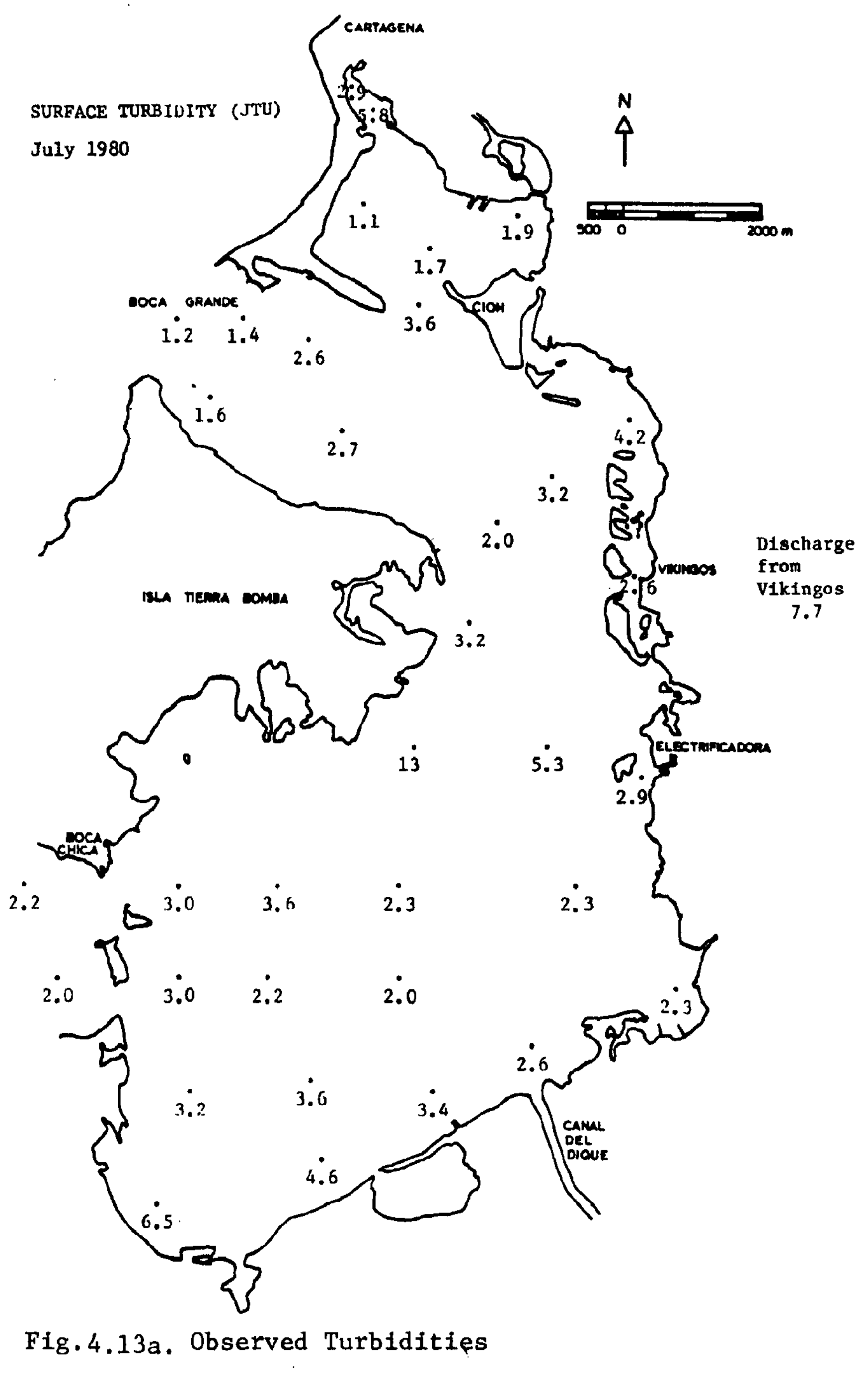



Fig.4.13a. Observed Turbidities

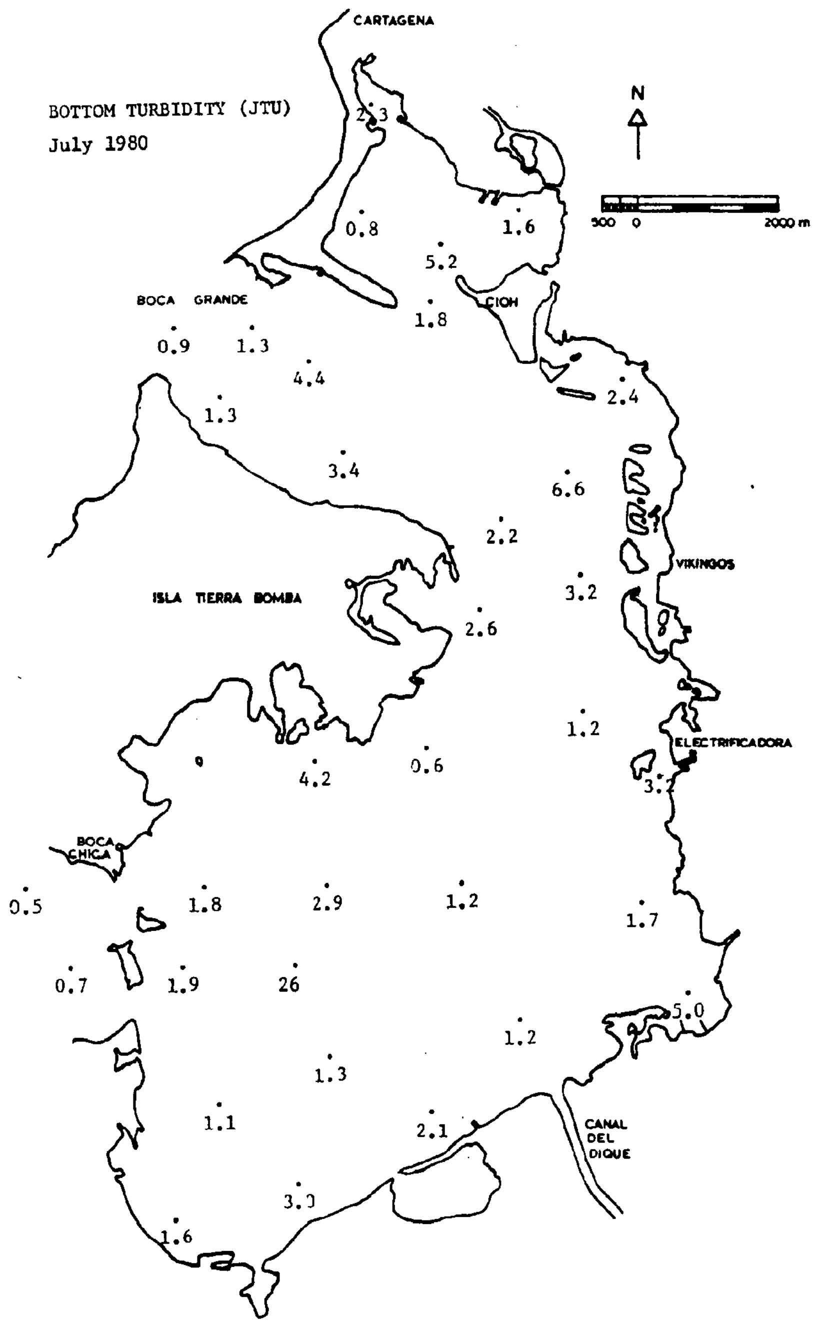



Fig. 4.13b. Observed Turbidities

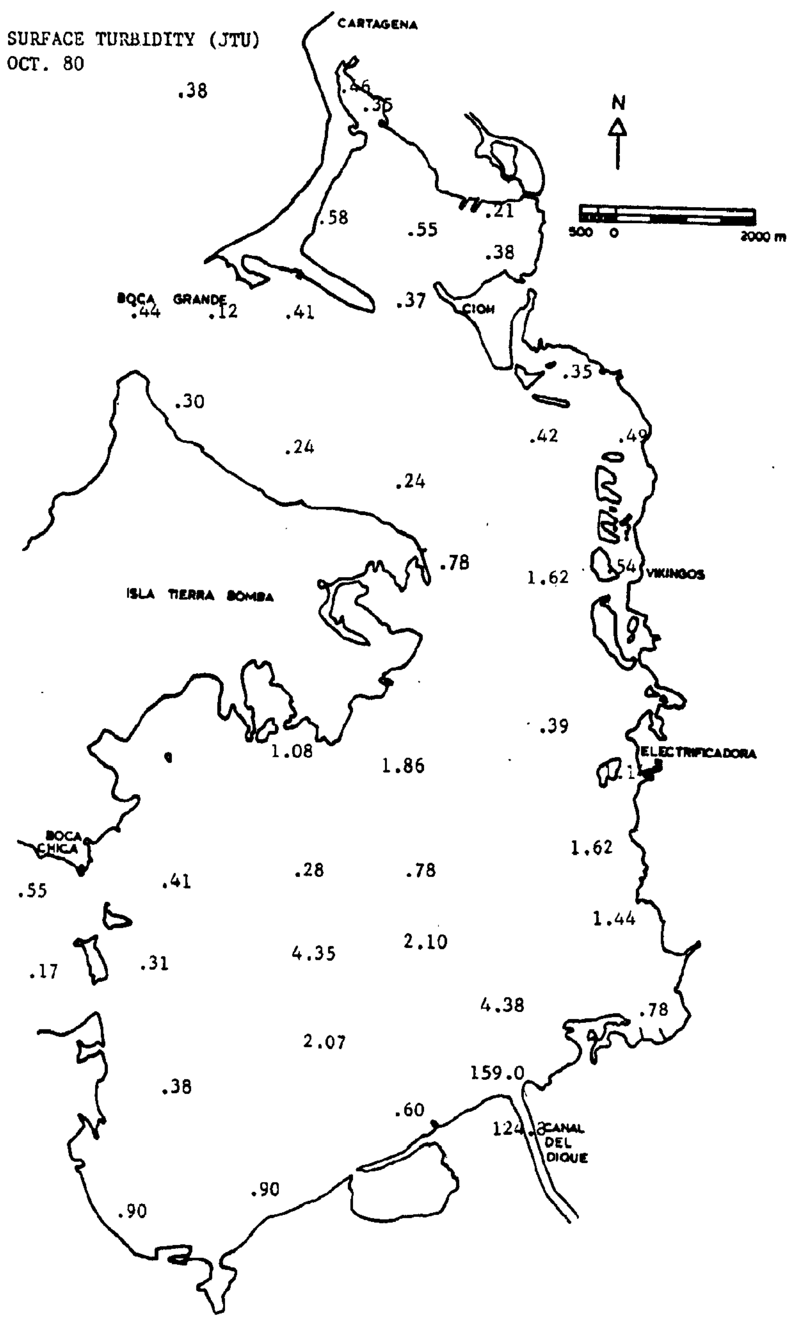



Fig. 4.13c. Observed Turbidities.

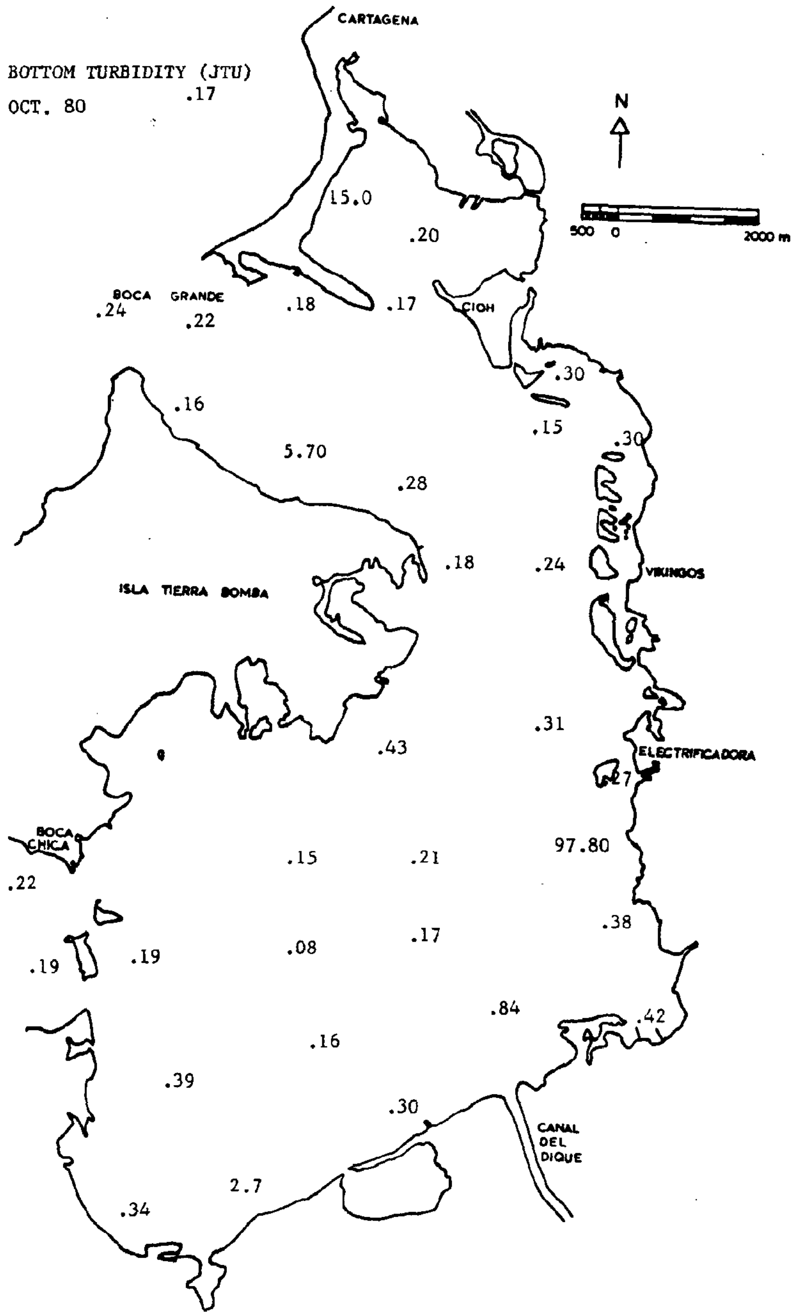



Fig. 4.13d. Observed Turbidities.

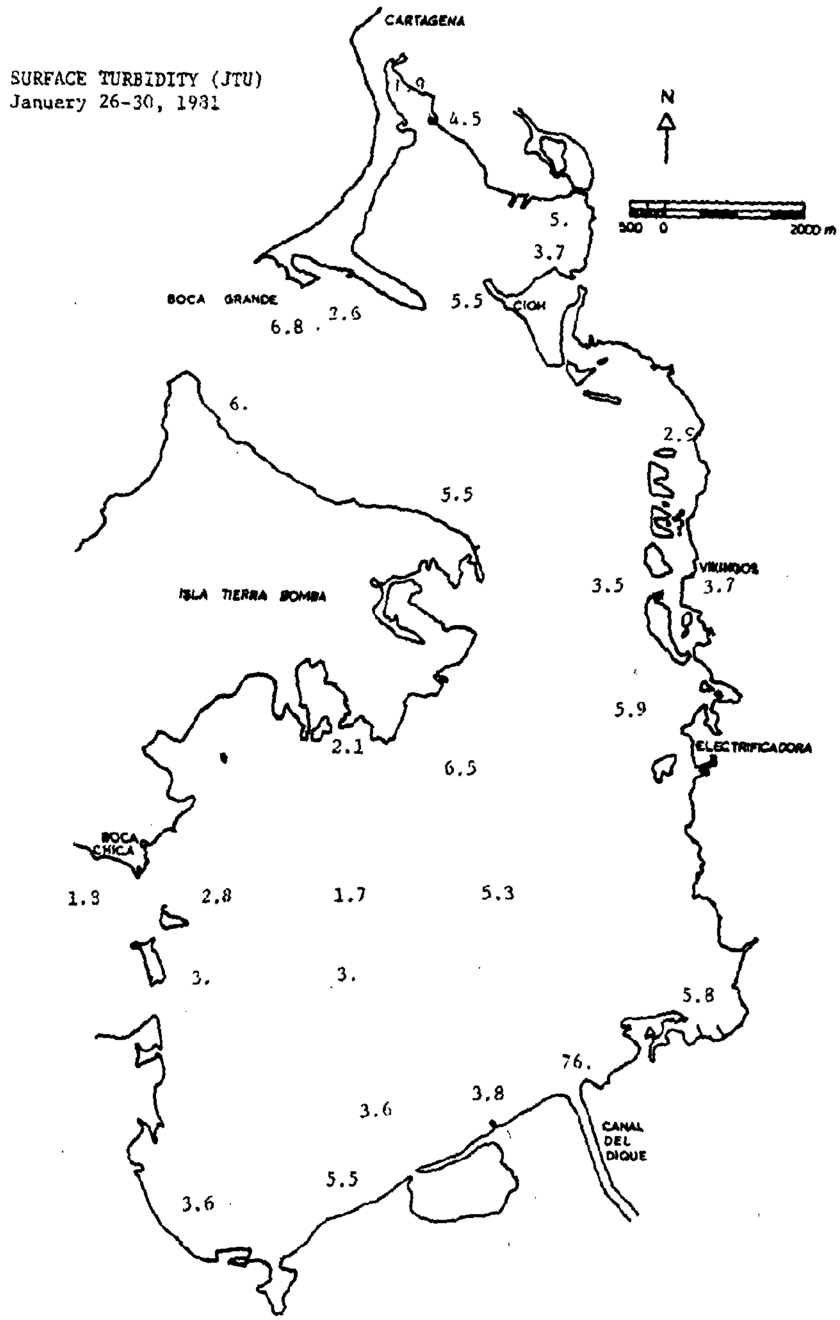



Fig. 4.13e. Observed Turbidities.

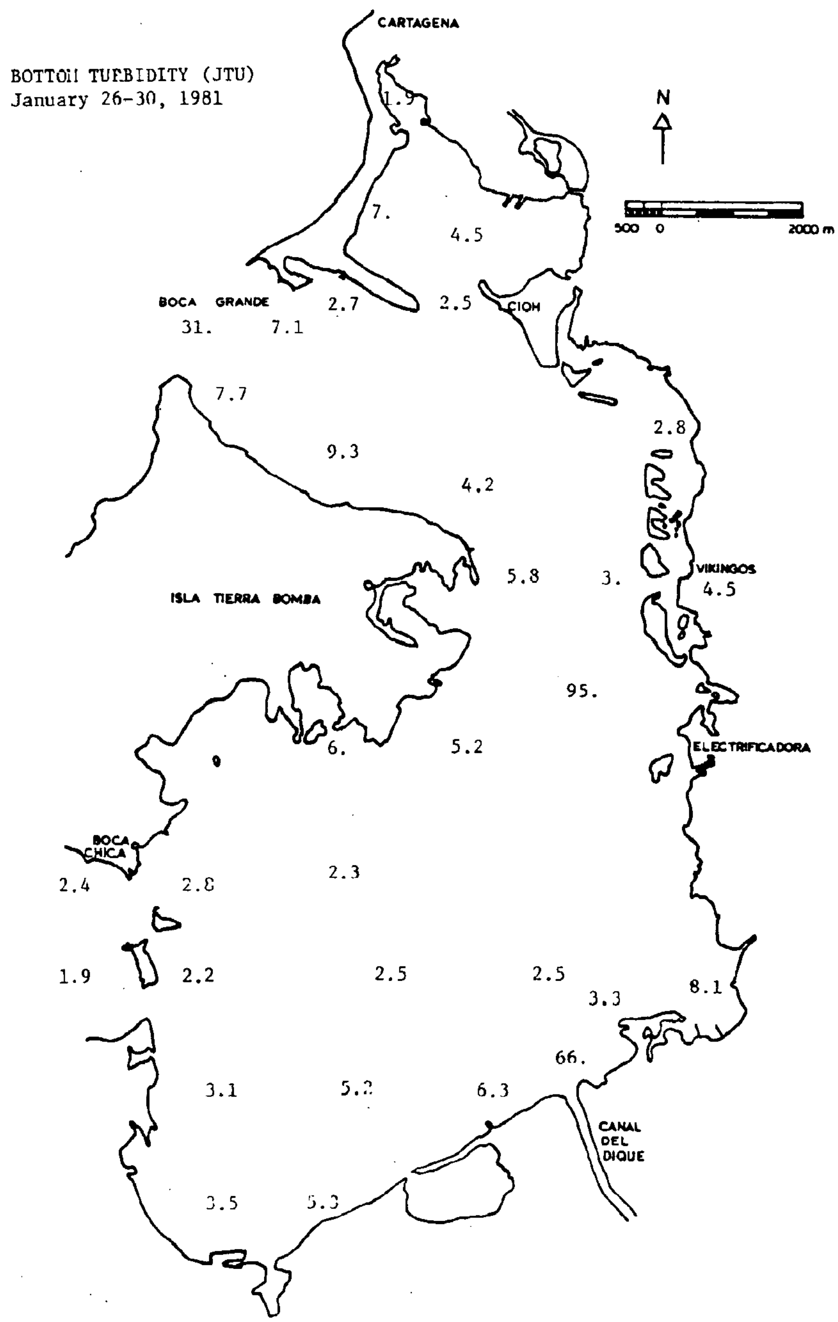



Fig. 4.13f. Observed Turbidities.

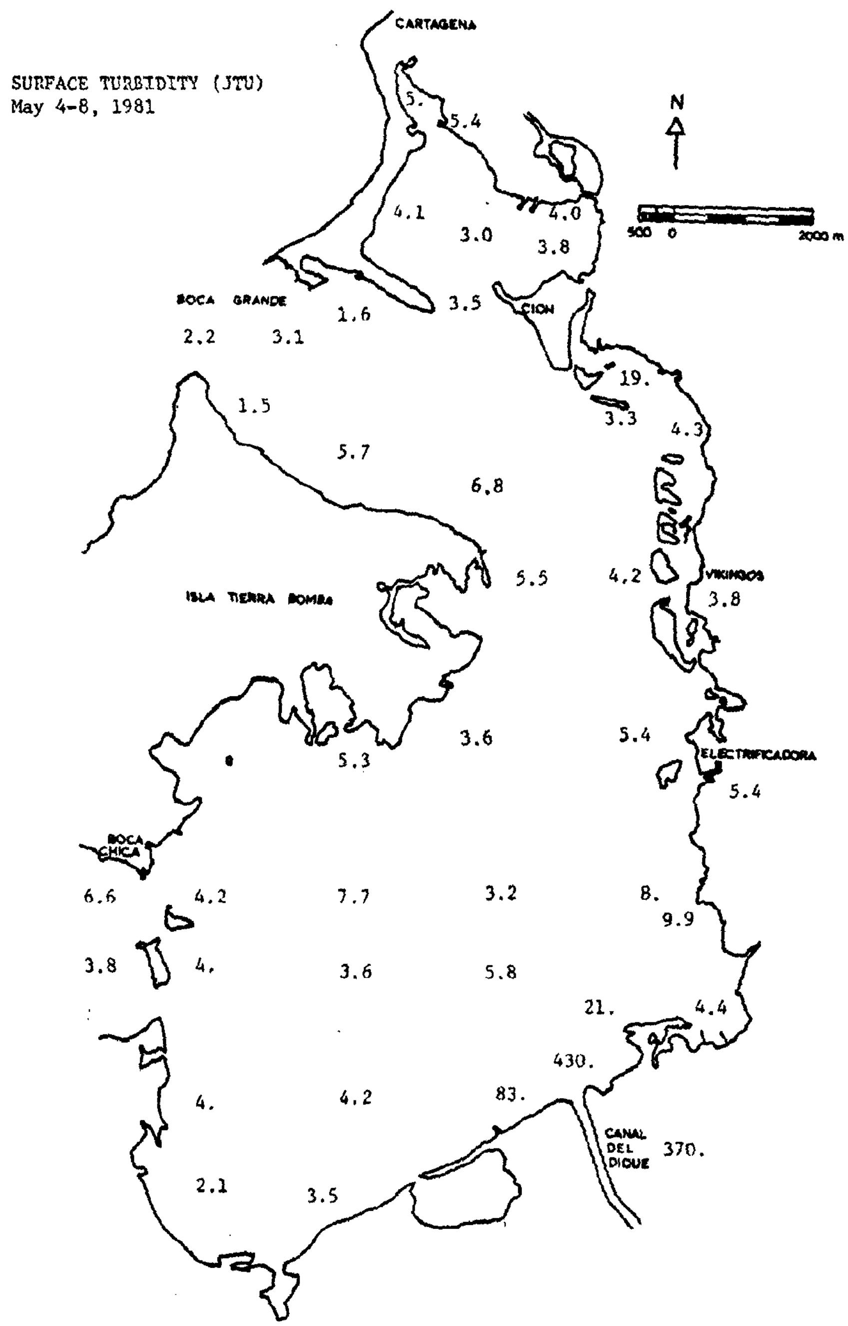



Fig. 4.13g. Observed Turbidities.

BOTTOM TURBIDITY (JTU)
May 4-8, 1981

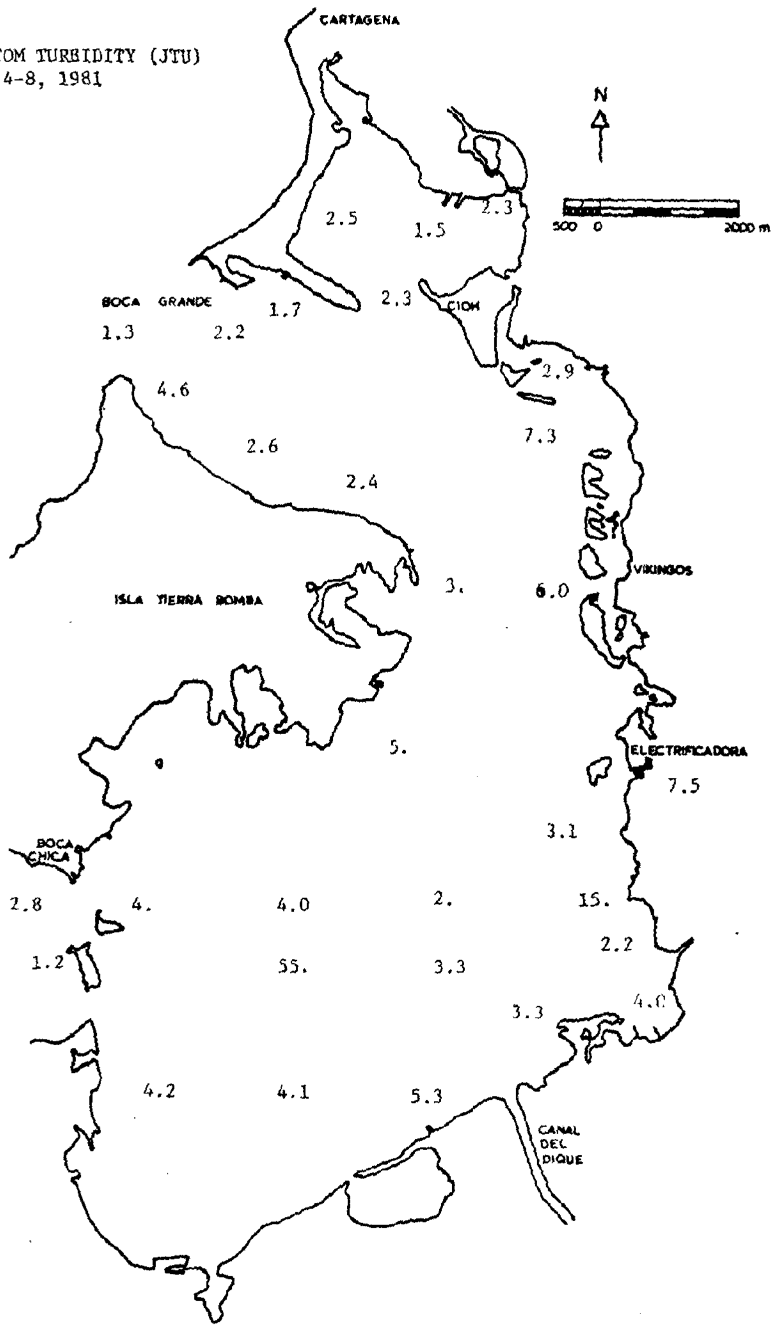



Fig. 4.13h. Observed Turbidities.

## 5. Analysis of Data

The most striking feature of the data which is of importance to the hydrodynamics of Cartagena Bay must be attributed to the vertical stratification. The exclusive cause of the stratification is due to the Canal del Dique inflow since other runoff and sewage disposal (about 1.2 $m^3$/sec) are comparably small.

Since stratification is a function of freshwater inflow and energy available for mixing, mainly from tides, it is useful to compare the freshwater inflow volume during a tidal cycle with the tidal prism. A typical inflow rate from Canal del Dique is $Q_F = 100\ m^3/s$ during the wet season. During one tidal cycle corresponding to 45000 sec this translates into a volume of $V_F = 4.5\ \ 10^6\ m^3$. The tidal prism, which is the volume of water entering the bay from the ocean during flood, can be approximately determined if the bay surface area and tidal harmonic constants are known. The surface area of the Bay is measured as $82.6 \cdot 10^6\ m^2$. Because of the relatively small size of the Bay compared to the tidal wave length, the water surface inside the Bay can with good approximation be assumed horizontal. Then, the tidal prism is simply the surface area multiplied by the tidal range, $P = A.H = 82.6 \cdot 10^6 \cdot 0.2 = 16.5 \cdot 10^6\ m^3$. Since P is only 4 times $V_F$ it is clear that the water in the Bay will be strongly stratified. Of course there are other times of the year when $V_F$ is very small and we would then expect to have a partially stratified or well-mixed situation. This qualitative analysis is well borne out by the measurements of salinity and temperature.

The effect of the stratification is clearly observed in the plot of drogue tracks, Fig. 4.8 which shows that the velocity in the surface layer is quite different from the velocity near bottom in both direction and magnitude.

A stably stratified water body requires energy to mix it up, otherwize it tends to reduce mixing compared to homogeneous water. This is of particular importance for Cartagena Bay which only has one narrow opening, Boca Chica deep enough to effect exchange with the ocean, while Boca Grande is only 1.5 to 2 m deep. It is therefore expected that the deeper denser layer of water in the Bay will exchange only very slowly. Some reprieve is obtained during winter months, the dry and windy season, when vertical mixing can take place.

Based on the measured salinity-temperature profiles, the Bay may be considered as a first approximation as a two layer system. The surface layer contains a significant amount of freshwater and has an increasing salinity with increasing depth below surface. At a certain depth the salinity becomes almost constant and this portion is denoted the bottom layer. It is apparent that the thickness and characteristics of the surface depend strongly on the Canal del Dique inflows. However, attempts to correlate these parameters failed because it was impossible to obtain the canal flow data from HIMAT, (Instituto Colombiano de Hidrologia, Meteorologia y Adecuacion de Tierras) for the period of our field work. The discharge rates for previous years shown in Fig. 4.1 are highly variable and do not allow a reasonable extrapolation to be made. The ST profiles seem to show a typical surface layer depth of about 8 m, which is fairly constant throughout the Bay.

A rough estimate of flushing time for the top layer can be made using an average freshwater inflow rate and the volume of freshwater in the Bay. Flushing time is here defined as an average time for exchanging all the water particles inside the Bay with ocean water.

A reasonable average salinity value for the surface layer is taken as 31 ppt. Assuming the ambient ocean salinity to be 36 ppt the volume of freshwater in the Bay

$$V_F = \frac{36-31}{36} \cdot V_T$$

where $V_T$ is the total volume of the top layer.

$$V_T = 82.6 \cdot 10^6 \cdot 8 = 661 \cdot 10^6 \text{ m}^3$$

Then $V_F = 92 \cdot 10^6 \text{ m}^3$ and the flushing time $T = V_F/Q_F = 920000$ sec = 11 days.

The flushing time in the bottom layer cannot be estimated in this manner and a guess can only be made that under stratified conditions the bottom layer exchanges very slowly, on the order of months.

The interior current meter measurements were to be used for more quantitative estimates of exchange rates and for verifying a numerical model.

A detailed analysis of the current meter data might provide more quantitative estimates of long term residual currents. However, a complete digitization of the data is a tremendous job which is beyond the scope of of this project. Only short periods have been plotted for analysis and model verification.

Figure 4.11 shows the N-S and E-W current components measured 4 m below surface over two days at Punta Arenas, station M1. A mixed tide is apparently discernible although other signals are quite strong in the N-S current. A typical tidal velocity amplitude in this direction is 6 cm/s. In the E-W component the tidal signal is very weak, however this is in a direction perpendicular to shore and therefore not surprising.

Figure 4.12 shows the N-S and E-W current components measured 20 m below surface at Punta Arenas. Little visual correlation can be found between the velocities and the tide also shown in the Fig.4.12. The large amplitude non-tidal current oscillations are possible due to meteorologically forced surges and internal waves. The time scale of these fluctuations is 2-3 hrs. An estimate of the period of an internal seiche can be obtained assuming the speed of the internal wave to be $c = \sqrt{\frac{\Delta\rho}{\rho} g \frac{H_1 H_2}{(H_1+H_2)}}$. $H_1$ and $H_2$ are the bottom and surface layer depths respectively. In our case we may take $H_1$ = 20 m and $H_2$ = 8 m. The density difference between the two layers is primarily governed by the salinity difference which we take as 36.5 - 31.0 = 5.5 ppt resulting in $\Delta\rho$ = 4.5 kg/m$^3$. With the characteristic values we obtain c = .5 m/s. As characteristic dimensions for the Bay we choose the length L = 14000 m and the width of Punta Arenas W = 2500 m. The corresponding seiche periods are $T_1$ = 15.6 hrs and 2.8 hrs. When a complete analysis of the current meter recordings is made, the importance of internal seiches will be better understood.

Turbidity data were collected in order to identify source areas and possibly to develop a qualitative idea of water motion and mixing characteristics. The Canal del Dique discharge is a large known source of suspended solids. At times, an extensive turbid plume can be observed on the surface in the southern part of the Bay. At other times, a very small turbid zone exists with an extremely sharp boundary to the ambient water. This has led us to believe that suspended solids occasionally make the canal discharge heavy enough to make it sink. Whether it actually becomes a dense bottom current or it spreads out at some depth below surface cannot be determined from the sparse data available. When sufficient sediment has settled down the plume would become lighter and start rising. In fact "pockets" of lower salinity water have been found at the surface within 2 to 3 km northeast of the canal mouth, which supports this theory. A much more detailed study, than possible in this project, of this particular problem could yield valuable information on the dynamic interaction between the canal discharge and the bay water. This information, in turn, could lead to a better understanding of the ecological impact of the canal and its effect on the general stratification of the Bay.

The recorded bottom and surface turbidities show a rapid decrease in turbidity away from the Canal del Dique. Two other source areas appear to be located on the east coast of the Bay and the Boca Grande area. No clear picture can be discerned from the data, possibly due to the fact that the water samples for each chemistry cruise were collected over a total period of 4-5 days. To be useful as a tracer, turbidity would probably have to be sampled daily over a period of 10-20 days.

Finally, the hypothesis that at times the Canal del Dique discharge may actually sink below the surface due to its suspended solid load has been made and partially substantiated with turbidity and salinity measurements. This phenomenon and the correlation between freshwater discharge and Bay stratification characteristics are interesting and important problems warranting further investigation. The data collected as part of this project should be useful as a basis for comparison in future studies and to evaluate long term changes in the Bay.

In summary, the field data show that the inflow from Canal del Dique causes the Bay to stratify into a two-layer type situation. Under these conditions, which can be expected to persist from March-April to November-December every year the water exchange rate in the surface layer is enhanced due to baroclinic circulation and a reasonable flushing time estimate is 11 days. During this period very little exchange takes place in the bottom, which is estimated to have a flushing time of the order of months.

In the winter months the Bay destratifies and although the flushing time may be greater than 11 days because of lack of density currents the well-mixed conditions allow significant vertical mixing to take place. The strong northerly winds during this period can provide the necessary energy input to effect mixing and to generate horizontal advection.

## 6. Model Formulation

Cartagena is one of the most important Colombian sea ports. The city itself has an interesting history going back to the initial colonization of the Spaniards, and is a popular seaside resort that attracts tourists from many places. A very diverse industry, taking advantage of the excellent port facilities, has also grown out especially along the eastern shoreline of the Bay. It is apparent that both tourist and other industries will expand considerably in the future and that the impact of future developments on the water quality in Cartagena Bay need to be considered in the regional plans. The present investigation is partially addressed towards this problem and one of the objectives is to develop a model that can describe the existing processes in the Bay as well as evaluate the effect of various changes in the controlling input parameters.

In 1974 Schaus developed a vertically averaged finite difference model of the Bay and considered the effect on circulation from various hypothetical modifications to the physical boundaries of the Bay. In view of our present knowledge with regard to the stratification of the Bay the work of Schaus is of little value in describing the actual dynamics of the water motion in the Bay.

A model describing the dynamics of a two layered water body has been developed by Wang and Connor (1975). This model is a reasonable approximation when a water body consists of two layers of fairly uniform but different densities. Although the surface layer in Cartagena Bay is not very uniform in density a two layer model may provide a first approximation explaining the salient features of the stratified flow problem. The velocity profiles taken at Boca Chica seem to indicate a twolayer structure while other profiles show more of a continuous shear distribution. These current measurements are subject to considerable uncertainty, as previously mentioned, because of wave action.

The model is based on the equations of motions integrated vertically within each layer. The interface is assumed to be a material surface through which momentum can be transferred and across which the pressure is continuous. Any exchange of mass between layers must be parameterized externally. Since vertical accelerations can be expected to be negligible compared with gravity, the hydrostatic approximation is also introduced. Finally the Boussinesq approximation is applied so that density variations are only included when multiplied by gravity. The equations then become for layer 1, (bottom):

$$H_{1,t} + q_{1x,x} + q_{1y,y} = 0$$

$$q_{1x,t} + (\bar{u}_1 q_{1x})_{,x} + (\bar{u}_1 q_{1y})_{,y} = f q_{1y} - (F_{1p} - F_{1xx})_{,x}$$

$$+ F_{1yx,y} + \frac{1}{\rho_1}\{\tau_{1x} - \tau_{0x} + p_1 \eta_{1,x} - p_0 \eta_{0,x}\}$$

$$q_{1y,t} + (\bar{v}_1 q_{1x})_{,x} + (\bar{v}_1 q_{1y})_{,y} = -f q_{1x} + F_{1xy,x}$$

$$- (F_{1p} - F_{1yy})_{,y} + \frac{1}{\rho_1}\{\tau_{1y} - \tau_{0y} + p_1 \eta_{1,y} - p_0 \eta_{0,y}\}$$

for layer 2, (top):

$$H_{2,t} + q_{2x,x} + q_{2y,y} = 0$$

$$q_{2x,t} + (\bar{u}_2 q_{2x})_{,x} + (\bar{u}_2 q_{2y})_{,y} = f q_{2y} - (F_{2p} - F_{2xx})_{,x}$$

$$+ F_{2yx,y} + \frac{1}{\rho_2}\{\tau_{2x} - \tau_{1x} + p_2 \eta_{2,x} - p_1 \eta_{1,x}\}$$

$$q_{2y,t} + (\bar{v}_2 q_{2x})_{,x} + (\bar{v}_2 q_{2y})_{,y} = - f q_{2x} + F_{2xy,x}$$

$$- (F_{2p} - F_{2yy})_{,y} + \frac{1}{\rho_2}\{\tau_{2y} - \tau_{1y} + p_2 \eta_{2,y} - p_1 \eta_{1,y}\}$$

where, see also Fig. 6.1

| | |
|---|---|
| $H$ | = layer thickness |
| $q_x, q_y$ | = discharge in x and y directions |
| $\bar{u}, \bar{v}$ | = x and y velocities |
| $f$ | = Coriolis parameter = $2\ \Omega \sin \phi$ |
| $\Omega$ | = radian frequency of earth rotation |
| $\phi$ | = latitude |
| $F_{xx}, F_{yx}, F_{yy}$ | = internal stresses |
| $\rho$ | = pressure |
| $\tau_x, \tau_y$ | = x and y shear stresses |
| $p$ | = pressure |
| $\eta$ | = surface elevation |

a comma denotes partial differentiation with respect to the following subscript(s) and the specific pressure force measures are

$$F_{1p} + \frac{1}{2} g H_1^{\ 2} + \frac{1}{2} g \frac{\Delta\rho_1}{\rho_{10}} H_1^{\ 2} + \frac{1}{\rho_{10}} p_1 H_1$$

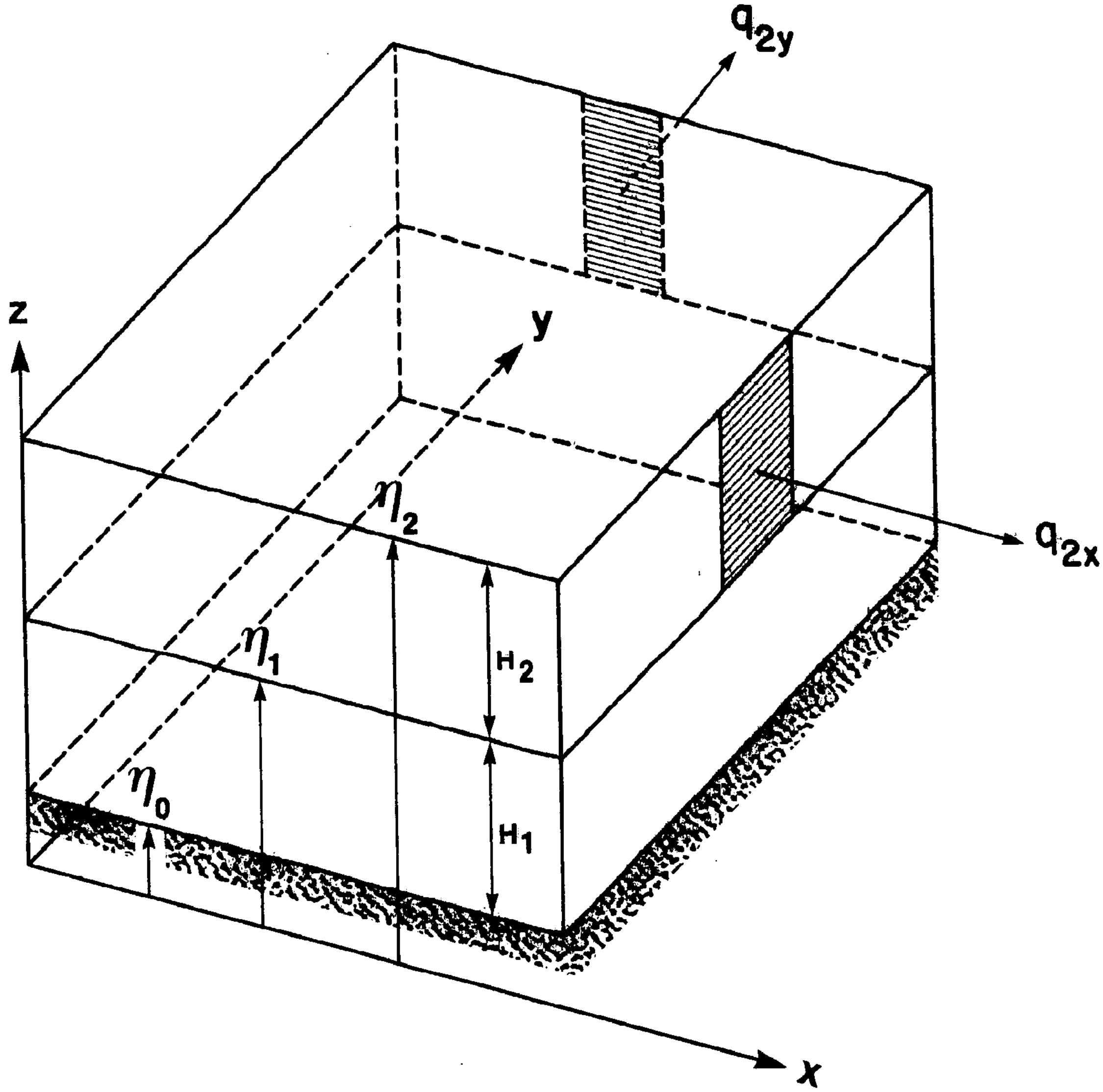



FIG. 6.1. Definition Sketch for Twolayer Model

The surface stress due to wind is determined from

$$\tau_2 = \rho_{air} C_D U_{10}^2$$

where $U_{10}$ is the wind speed 10 m above the surface. The drag coefficient $C_D$ can be calculated from the empirical formula

$$C_D = (1.1 + 0.0536 \cdot U_{10}) \cdot 10^{-3} \quad U_{10} \text{ in m/s}$$

Finally the internal stress terms which arise due to averaging over turbulent time scales and the vertical integration are parameterized using an eddy viscosity formulation.

$$F_{x_i x_y} = E_{ij} \left(\frac{\partial q_j}{\partial x_i} + \frac{\partial q_i}{\partial x_j}\right) \qquad \left.\begin{matrix} i \\ j \end{matrix}\right\} = 1,2$$

with subscripts denoting x (1) and y(2) direction.

The boundary condition for the problem consist of specified flow perpendicular to the boundary or surface elevations.

The complexity of the equations require a numerical technique in order to obtain a solution. The finite element method has been chosen here because it allows conformity with a complicated geometry using relatively few grid points.

$$F_{2p} = \frac{1}{2} gH_2{}^2 + \frac{1}{2} g \frac{\Delta\rho_2}{\rho_{20}} H_2{}^2 + \frac{1}{\rho_{20}} p_2 H_2$$

The pressures at the interface and bottom are

$$p_1 = p_2 + \rho_{20} g H_2$$

$$p_0 = p_2 + \rho_{20} g H_2 + \rho_{10} g H_1$$

Bottom shear stress is parameterized as

$$\frac{\tau_{0x}}{\rho_{10}} = C_f (q_{1x}{}^2 + q_{1y}{}^2)^{1/2} \frac{q_{1x}}{H_1{}^2}$$

$$\frac{\tau_{0y}}{\rho_{10}} = C_f (q_{1x}{}^2 + q_{1y}{}^2)^{1/2} \frac{q_{1y}}{H_1{}^2}$$

where the friction coefficient is taken as the standard Darcy Weisbach factor multiplied by 8.

The interfacial shear stresses are related to the square of the velocity difference of the two layers

$$\frac{\tau_{1x}}{\rho_{10}} = C_1 \{u_1 - u_2)^2 + (v_1 - v_2)^2\}^{1/2} (u_2 - u_1)$$

$$\frac{\tau_{1y}}{\tau_{10}} = C_1 \{(u_1 - u_2)^2 + (v_1 - v_2)^2\}^{1/2} (v_2 - v_1)$$

where $C_1$ is an interfacial shear stress coefficient. The magnitude of $C_1$ is not well-known except that it depends on the density difference between layers and that its order of magnitude is close to that of $C_f$.

## 7. Model Adaptation to Cartagena Bay

The main model modifications, compared to earlier applications in Massachusetts Bay, consist of incorporating the capability of using different boundary conditions in top and bottom layers and the possibility of excluding elements in the bottom layer grid where the total water depth is so small that a dense bottom does not exist.

The first change is necessary to treat the Boca Grande entrance properly, since here the top layer has free exchange with the ocean while the bottom layer essentially is bounded by land in the form of a submerged plateau.

The second modification allows a better approximation of the actual bathymetry and especially the shallow water near the edges of the Bay.

The finite element grids consisting of linear triangles for top and bottom layers are shown in Fig . 7-1 . The intiial depth of the surface layer is taken as 6 m throughout.

Although the real depth at Boca Grande is only a few meters, the depth of the top layer in the model is controlled by the interface position. The error incurred thereby should be small since the velocities in this area are fairly small. The effect of the submerged barrier is approximately simulated by using an increased friction factor of 0.0035 and 0.0030 in the row of elements closest to the boundary. In the remaining area a constant friction factor of 0.0025 which approximately corresponds to a Manning coefficient of 0.025 in 17 m of water is used.

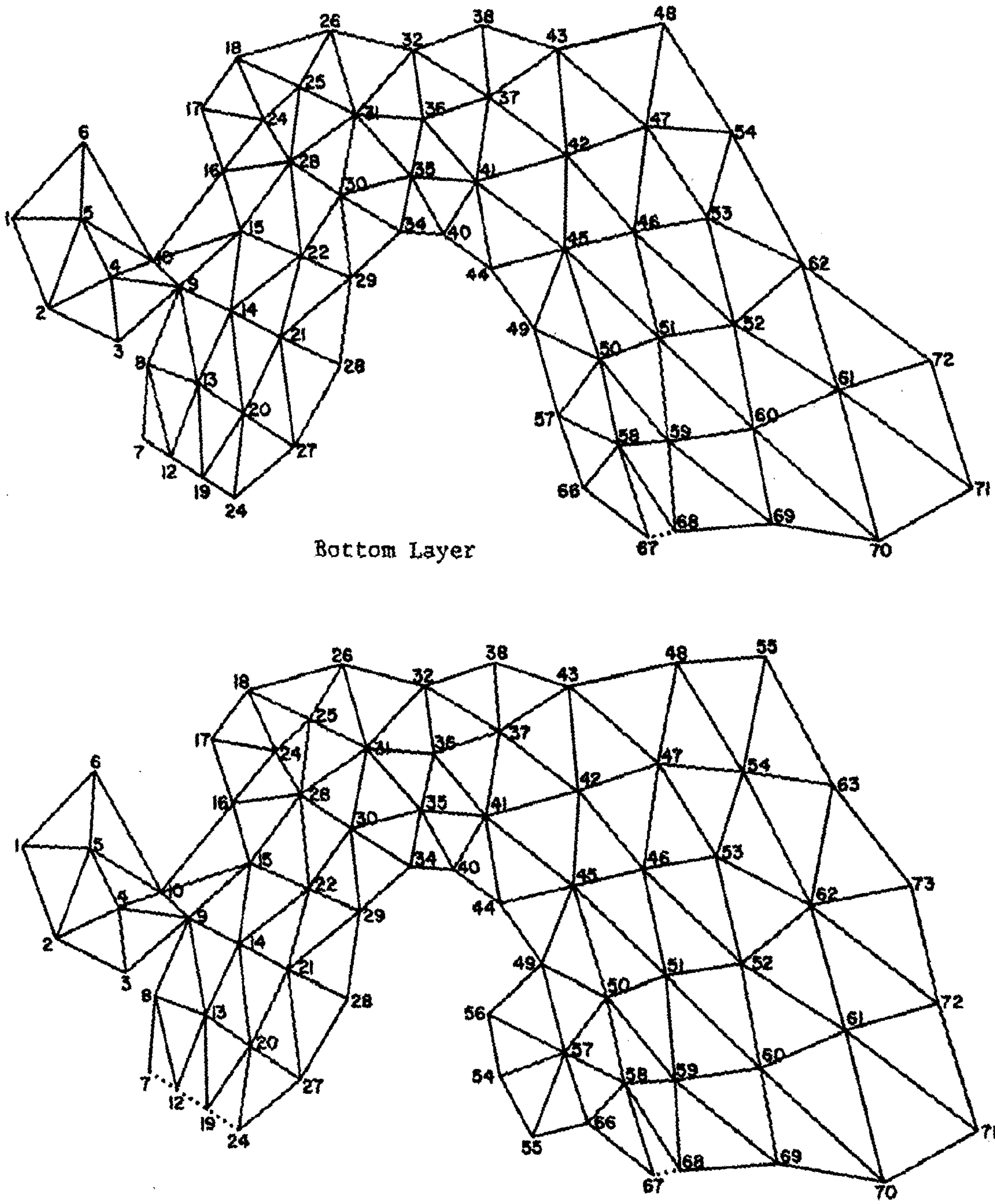



Fig. 7.1. Finite element grids for Cartagena Bay.

The Canal del Dique discharge is accommodated as a point source of strength 75 $m^3/s$ located at the mouth of the Canal.

The finite element grid employed consists of 101 elements and 71 nodes with an average node distance of between 700 to 1000 m. The grid is a compromise between a desire to resolve all important bathymetric or geometric features and efficiency of computation. The time step used for the computations is 50 sec while the courant condition using a distance of 1000 and a depth of 28 m is $1000/\sqrt{9.81 \cdot 28} = 60$ sec. Computation of one time step on a UNIVAC 1100 system takes approximately 1.5 sec CPU and 40 K words of memory.

## 8. Model Applications

Three model simulations are executed of the typical forcing conditions in order to compare with field data and to determine transport characteristics for situations where data are not available.

### 8.1 Tidal Flow

The most consistent forcing of the Bay is provided by the astronomical tides. In order to simulate tidal currents appropriate boundary conditions must be prescribed. A mean tidal amplitude of 0.12 m is applied to the surface of the open boundaries. The tidal curve is assumed to be a sinusoid with a period of 45000 sec. Since the measured tides do not provide enough resolution to determine whether phase lags less than about 30 min exist two tests are made in the model. In the first run it is assumed that the tides at Boca Grande and Boca Chica are in perfect phase. For the second run Boca Chica is assumed to lag behind Boca Grande by 30 min.

The results are only moderately sensitive to such variations and all the runs described in this report incorporate the 30 min lag. Similarly, a constant discharge of 75 $m^3/s$ is included as a simple source at the location of the mouth of Canal del Dique in all the simulated runs.

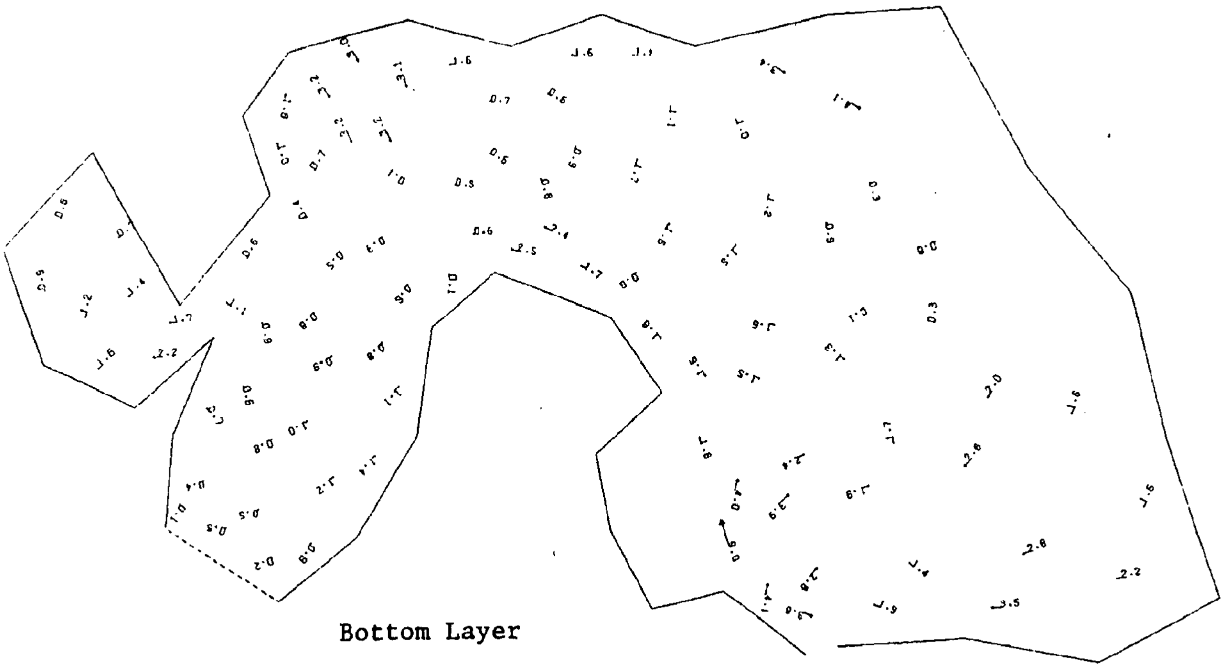
The boundary conditions in the bottom layer consist of prescribed normal flow equal to zero at Boca Grande and a sinusoidally oscillating interface at Boca Chica. The amplitude for this oscillation is arrived at by scaling the surface amplitude by the relative depth equal to bottom layer depth divided by total depth or $9/15 \cdot 0.12 = 0.07$ m. The interface is assumed in perfect phase with the surface at this locations.

The model is stated from "cold", i.e. horizontal surface and interface with zero velocity everywhere, and allowed to dissipate this initial condition during the first 18000 sec.

The result of the tidal simulation in which an interface shear coefficient of 0.003 is used are shown in Figs. 8.1a to 8.1e.

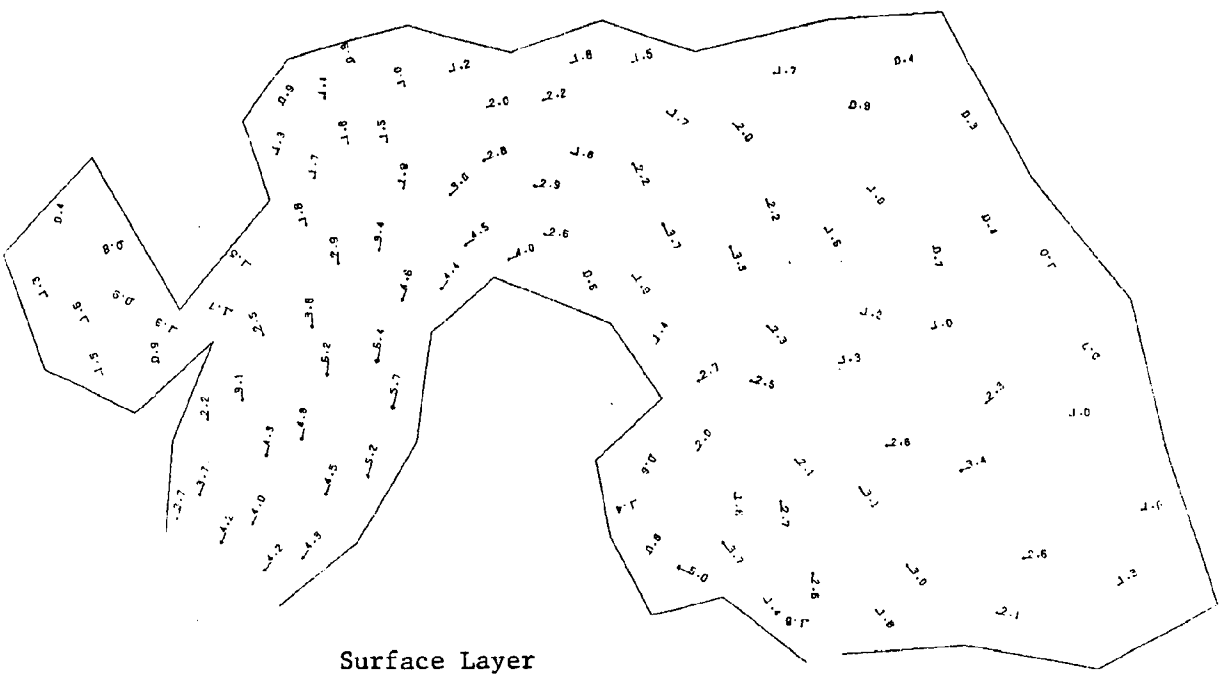
Comparing with the current meter results in the Punta Arenas area, the model predicts somewhat smaller speed magnitudes, probably partly due to the use of a mean tidal range of 0.24 m. However, the model also shows fluctuations within a tidal period similar to those found in the observations. It appears that an internal seiche mode is excited by the tides.

The hypothetical trajectories of particles in top or bottom layers are computed from the model results and shown in Fig. 8.2 which cover a 2.5 day period. These trajectories verify the previous findings that exchange in the bottom layer are very slow, while flushing in the top layer is of the order of 10 to 20 days with somewhat longer times applying to the southern part of the Bay. Perhaps the biggest surprise is found in the trajectory of the particle in the top layer just to the southeast of the Boca Chica opening, which shows a net motion away from the ocean. All the other particles in the top layer move towards the ocean as would be expected due to the constant freshwater inflow. A possible explanation could be that due to the topography, which in this



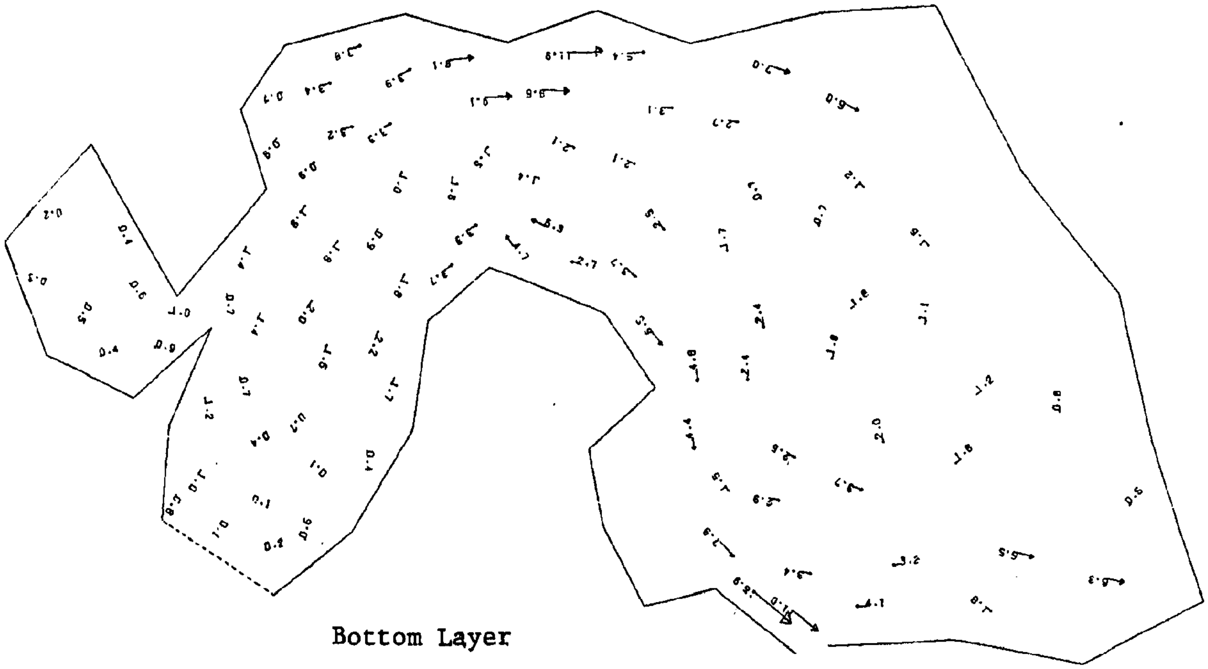
Bottom Layer

Speed in cm/s



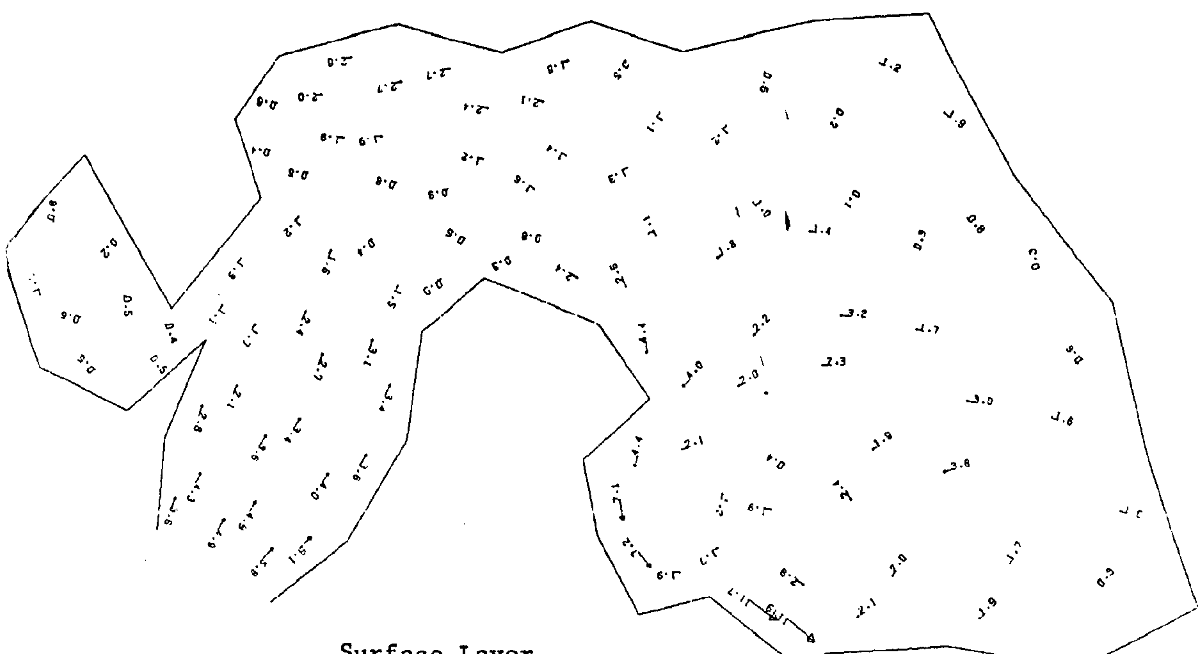
Surface Layer

Fig. 8.1a. Predicted tidal currents in Cartagena Bay.
Time = LW + 9000 sec.



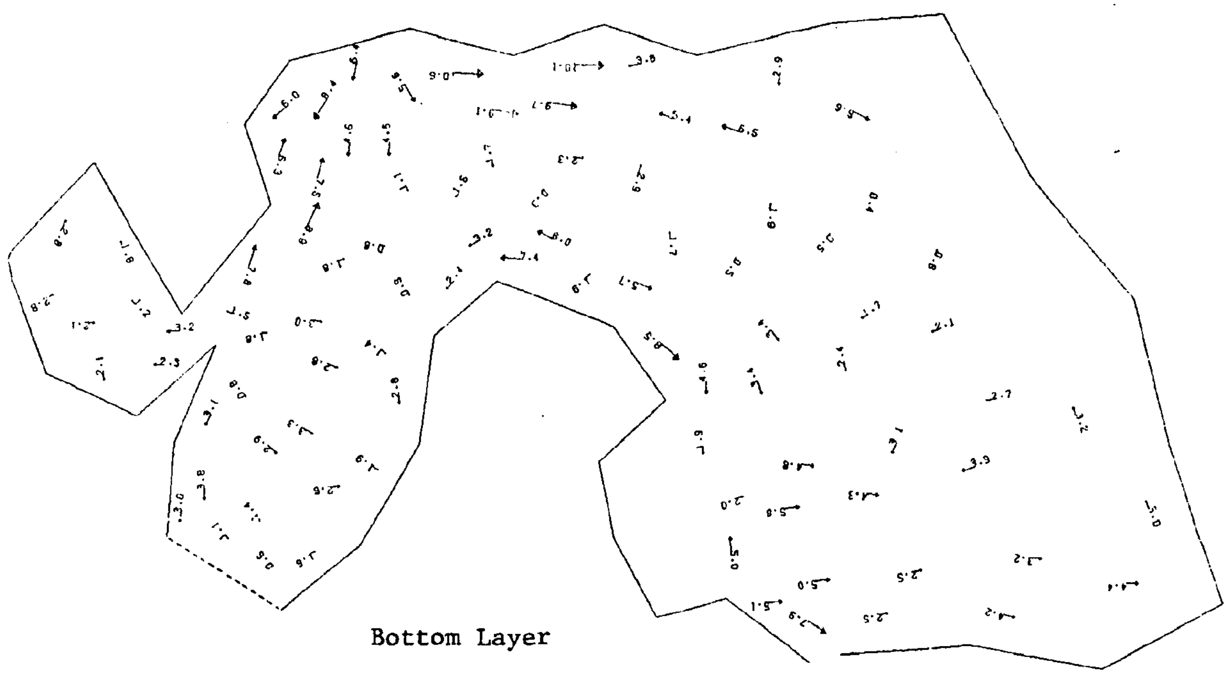
Bottom Layer

Speed in cm/s



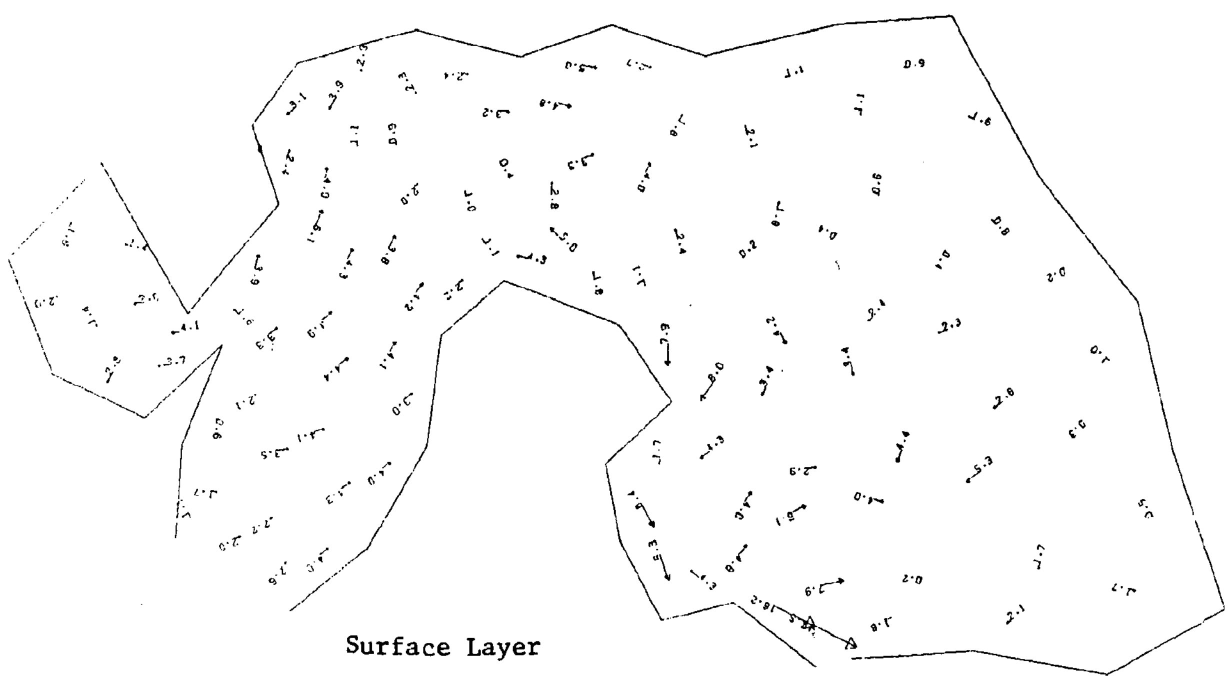
Surface Layer

Fig. 8.1b. Predicted tidal currents in Cartagena Bay
Time = LW + 18000 sec.



Bottom Layer

Speed in cm/s



Surface Layer

Fig. 8.1c. Predicted tidal currents in Cartagena Bay

Time = LW + 27000 sec.

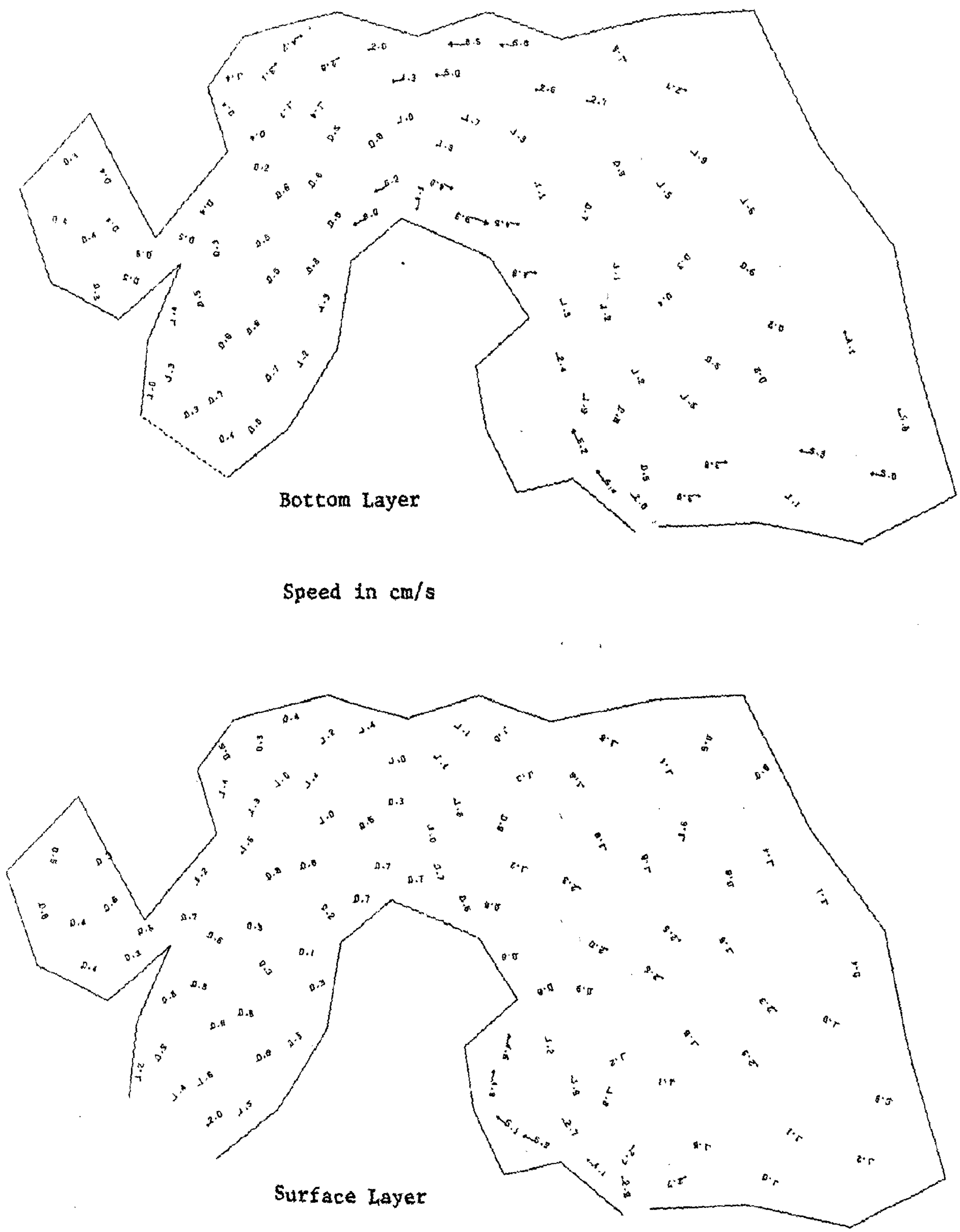
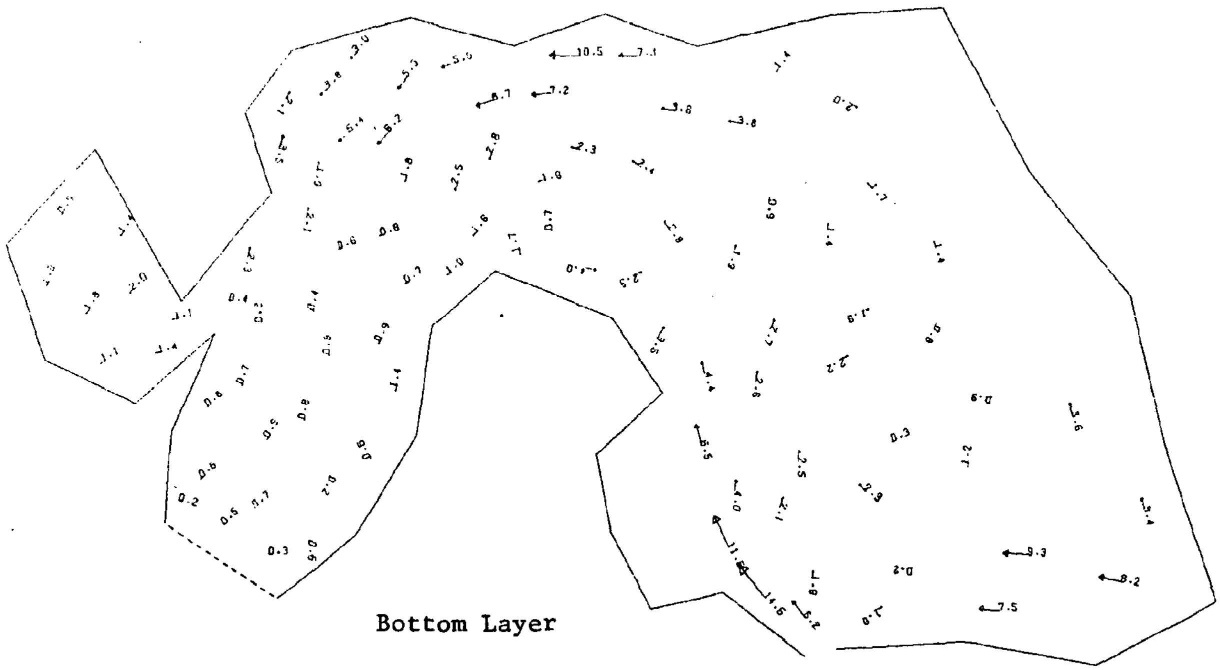
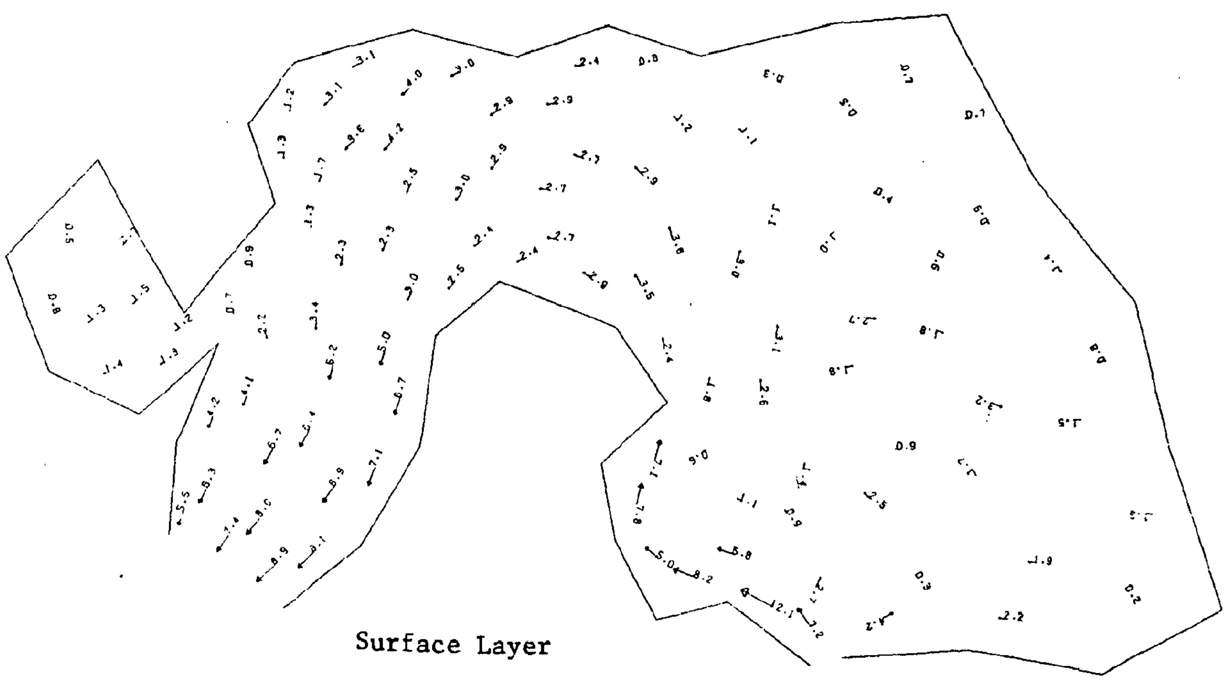



Fig. 8.1d. Predicted tidal currents in Cartagena Bay.
Time = LW + 36000 sec.



Bottom Layer

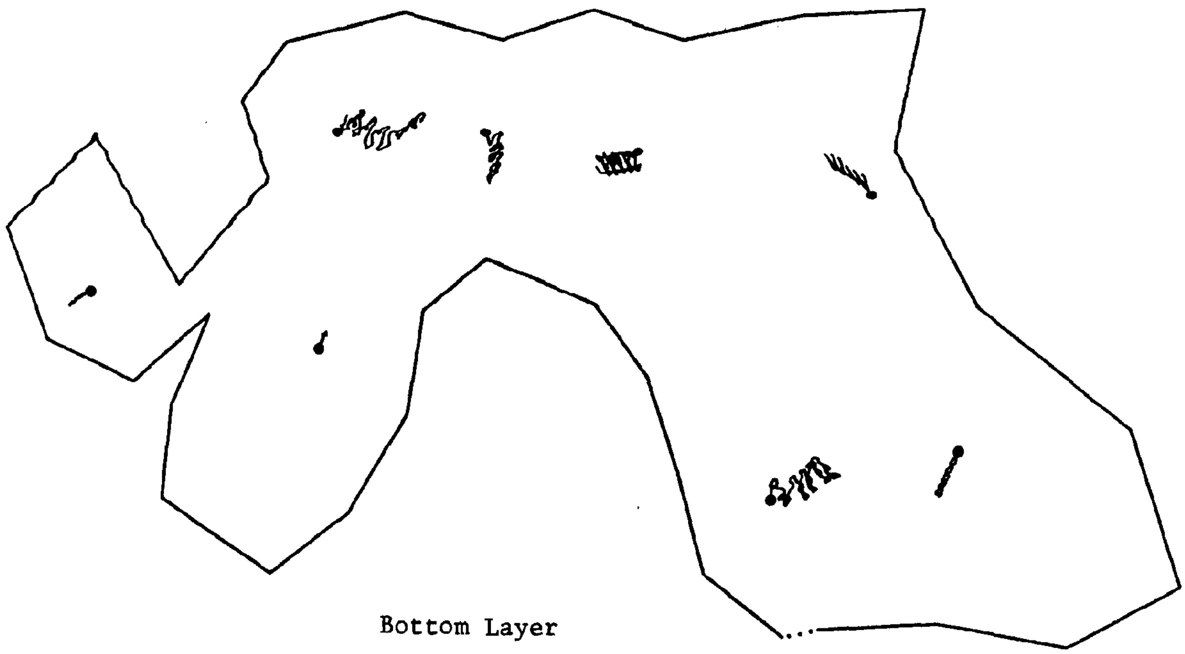
Speed in cm/s



Surface Layer

Fig. 8.1e. Predicted tidal currents in Cartagena Bay.

Time = LW + 45000 sec.



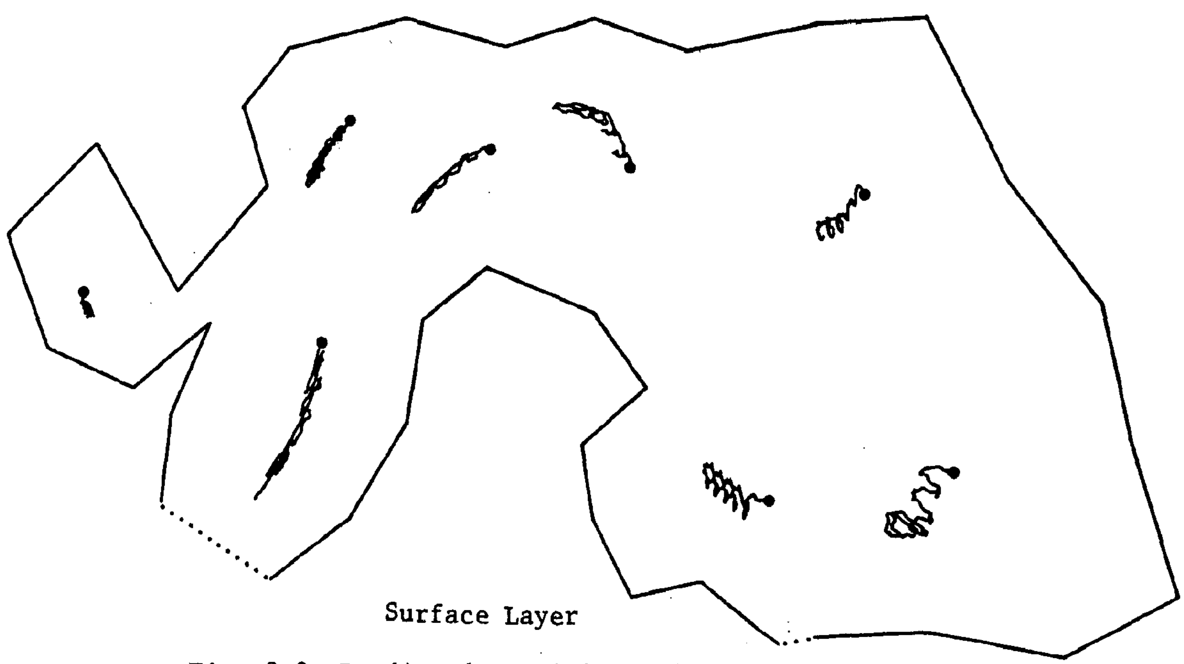




Fig. 8.2 Predicted particle trajectories for tidal forcing.

area is complicated by islands, an embayment and several channels, a local eddy occurs in the residual currents. More field data should be collected to verify this phenomenon.

8.2 Southwesterly Winds

During most of the year, when the Bay is stratified, the winds are moderate and variable. At times, a sea breeze is noticeable. The most dominant wind direction seems to be from the southwest. In order to evaluate the effect of such winds the model is forced by a wind of 5 m/s ($\simeq$ 10 kn) from due SW. Tidal flow and freshwater inflow of 75 $m^3/s$ are included as before. The wind drag coefficient $C_D = (1.1 + 0.0536 \cdot 5.0)10^3 = 0.001368$, and the wind stress is 0.00004 $N/m^2$.

The computed velocity fields are shown in Figs. 8.3 a-8.3e. The most conspicuous differences compared to the pure tidal flow case are best demonstrated by the particle trajectories over 2.5 days shown in Fig. 8.4. There is an obvious southerly migration of particles in the bottom layer, while the surface trajectories tend to follow the wind. It should be noted that no attempts were made to adjust the ocean boundary conditions to account for wind effects. The model is started from "cold" and run for 60000 sec, and in plotting the particle trajectories it is assumed that the velocity field computed during the latter 45000 sec repeat continuously. Although, such an assumption cannot be expected to be fully correct, the trend indicated by the trajectories should at least represent the water motion during the initial period of wind forcing. In the future it would be interesting

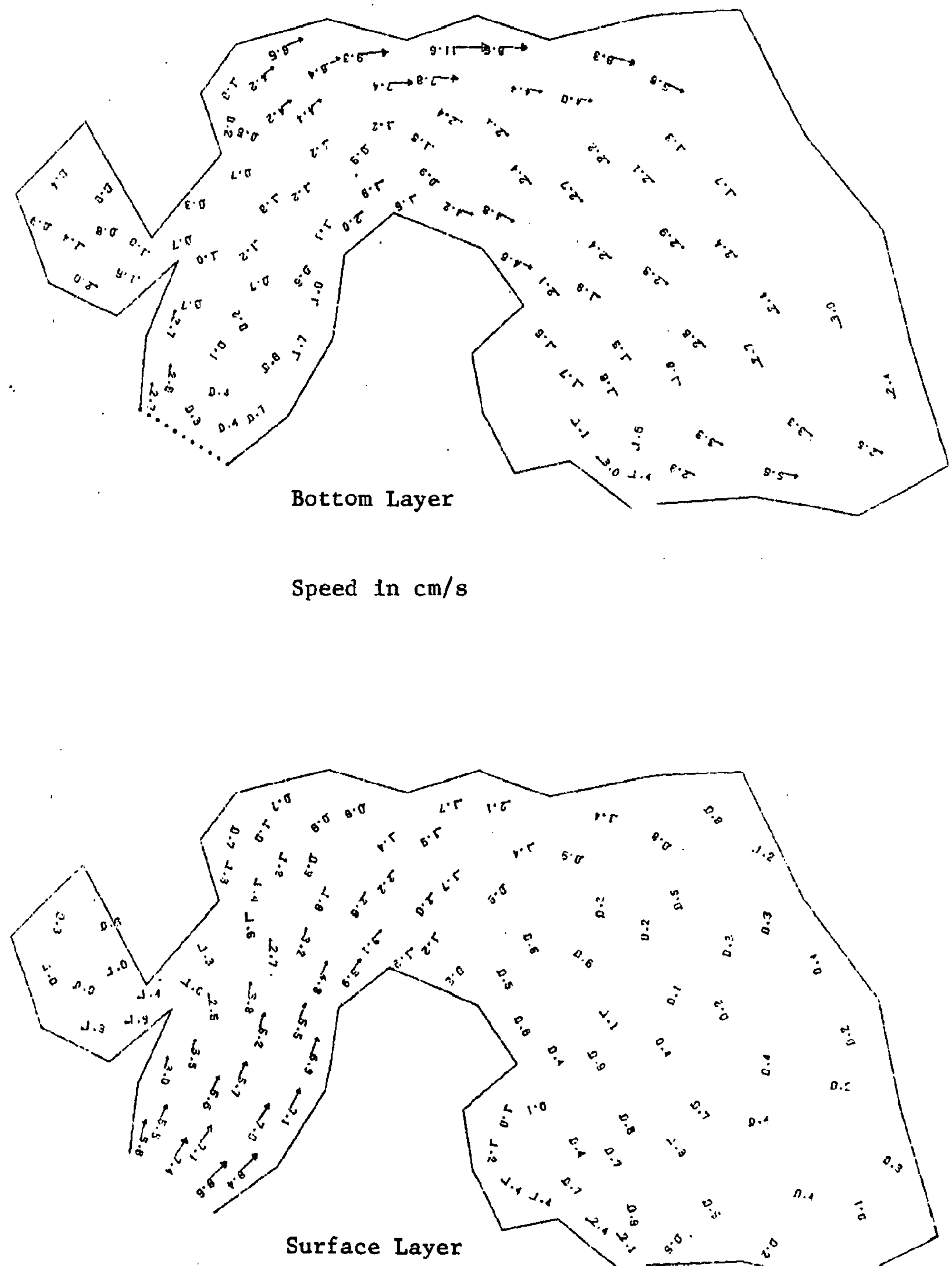



Fig. 8.3a. Predicted currents in Cartagena Bay. Tide and SW wind.
Time = LW + 9000 sec.

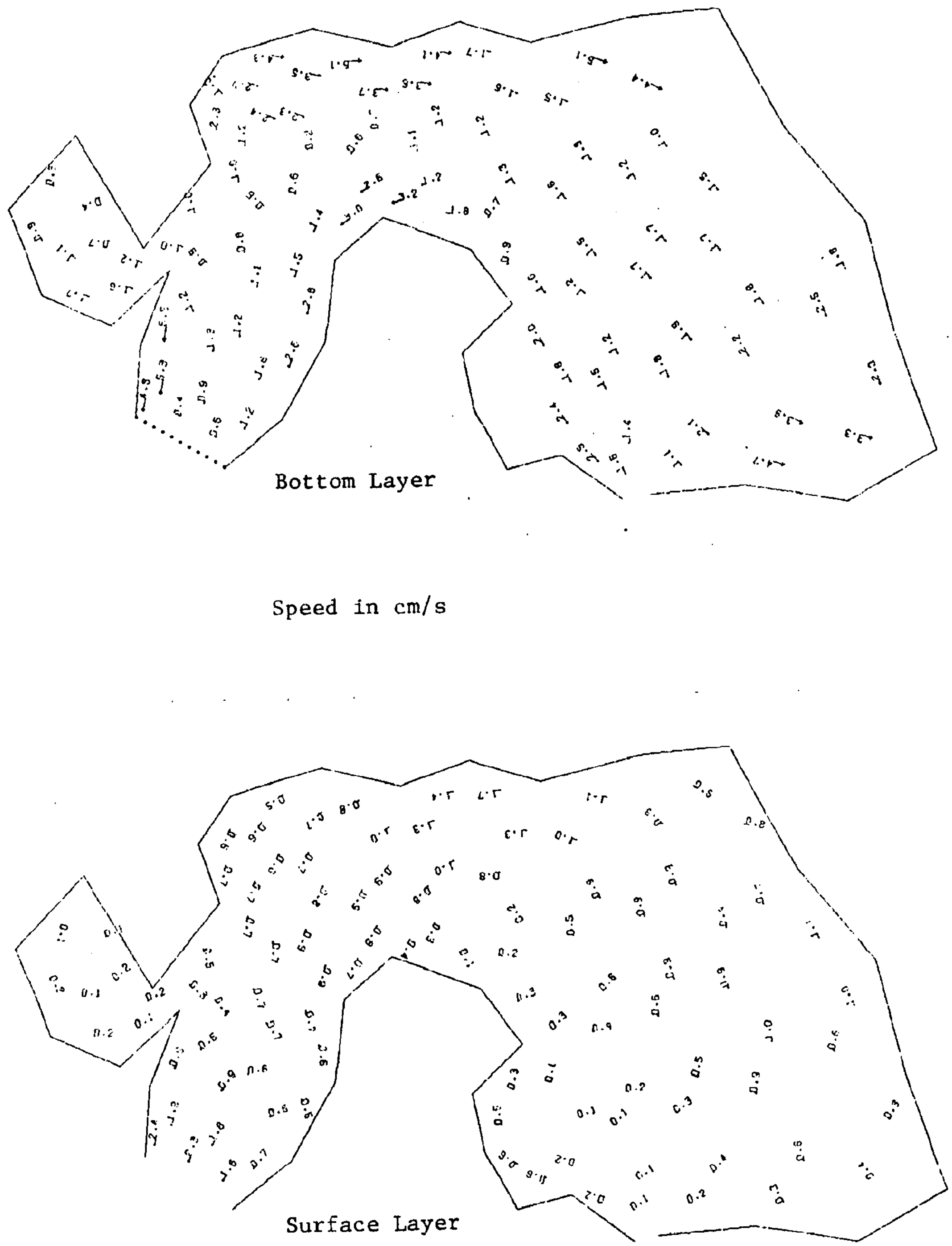
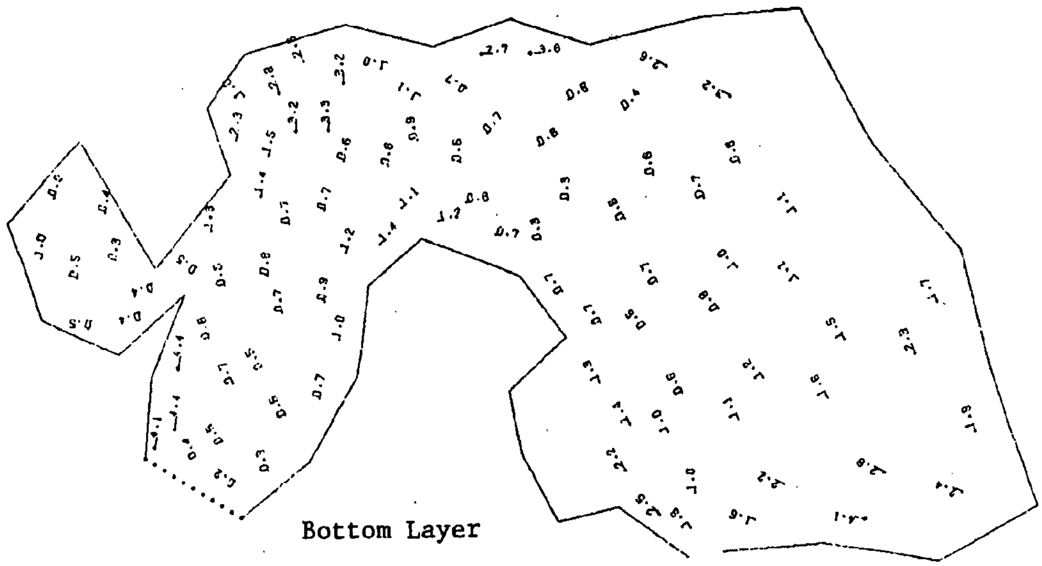
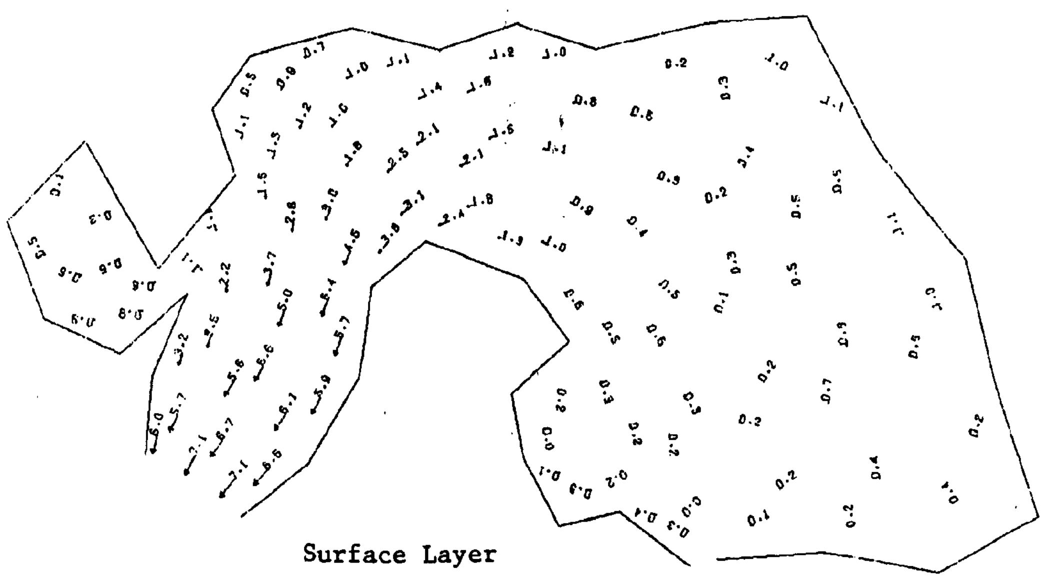



Fig. 8.3b. Predicted currents in Cartagena Bay. Tide and SW wind.
Time = LW + 18000 sec.



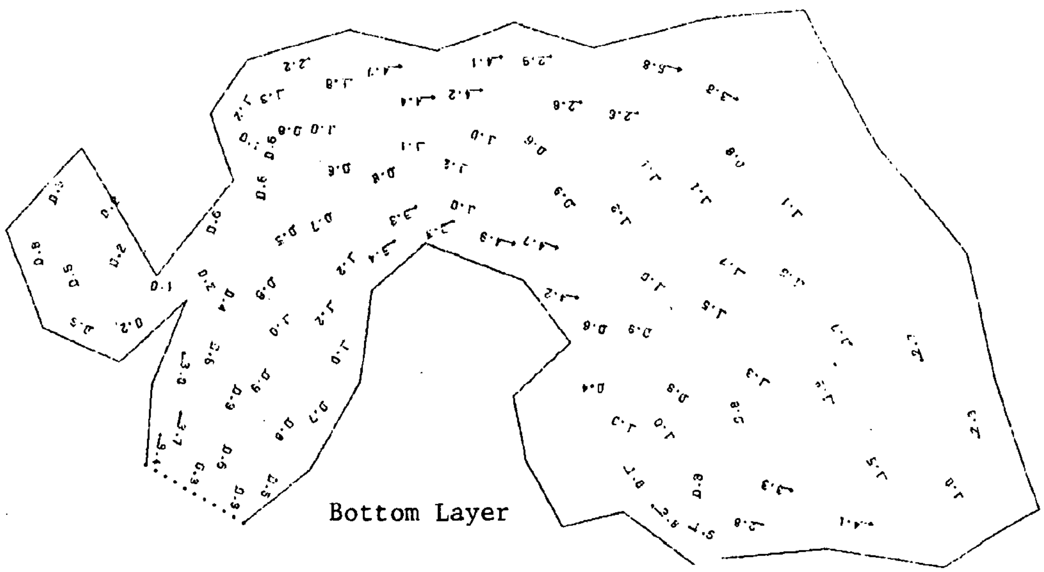
Bottom Layer

Speed in cm/s



Surface Layer

Fig. 8.3c. Predicted currents in Cartagena Bay. Tide and SW wind. Time = LW + 27000 sec.




Speed in cm/s

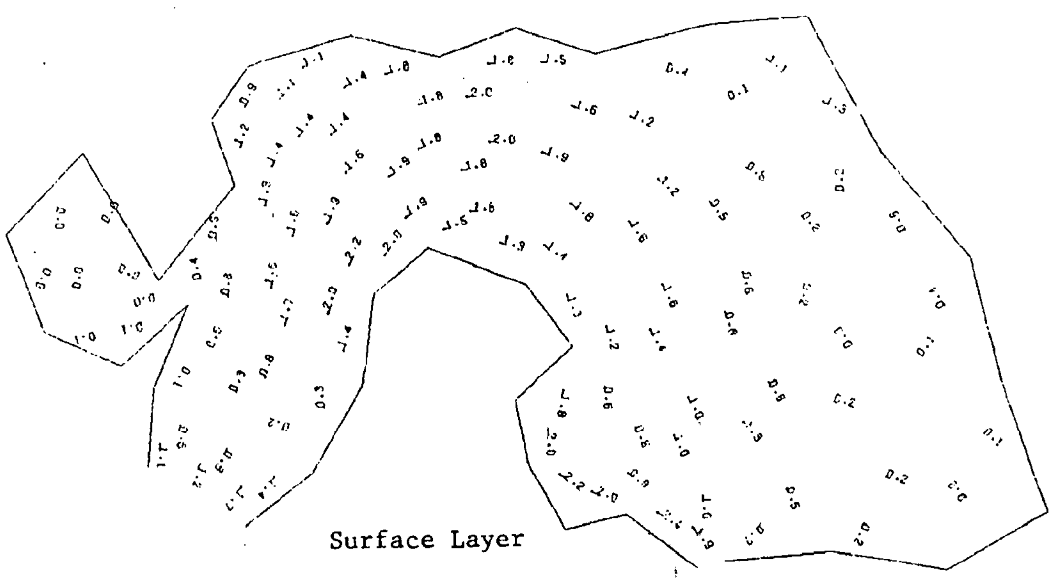



Fig. 8.3d. Predicted currents in Cartagena Bay. Tide and SW wind. Time = LW + 36000 sec.

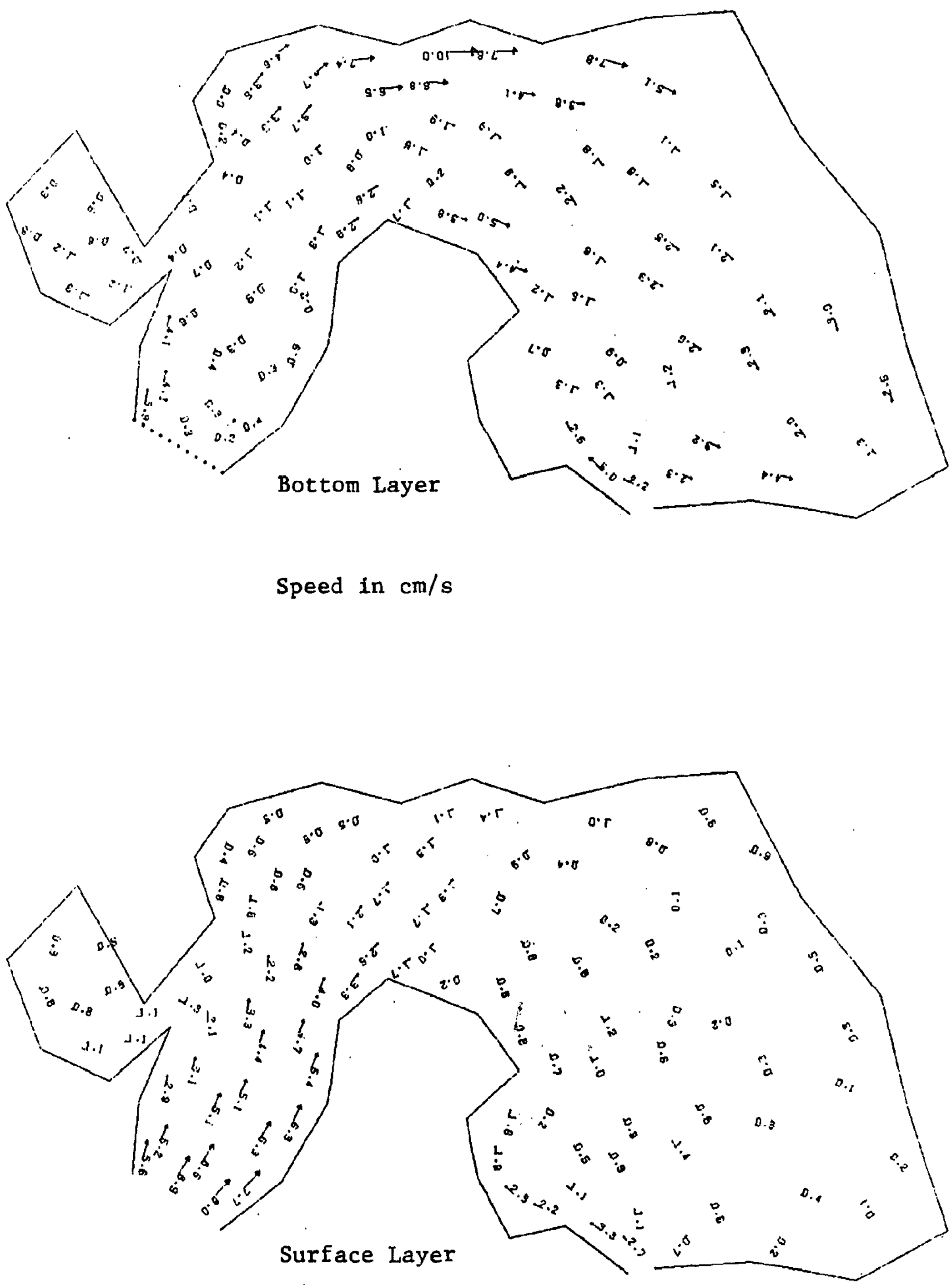



Fig. 8.3e. Predicted currents in Cartagena Bay. Tide and SW wind. Time = LW + 45000 sec.

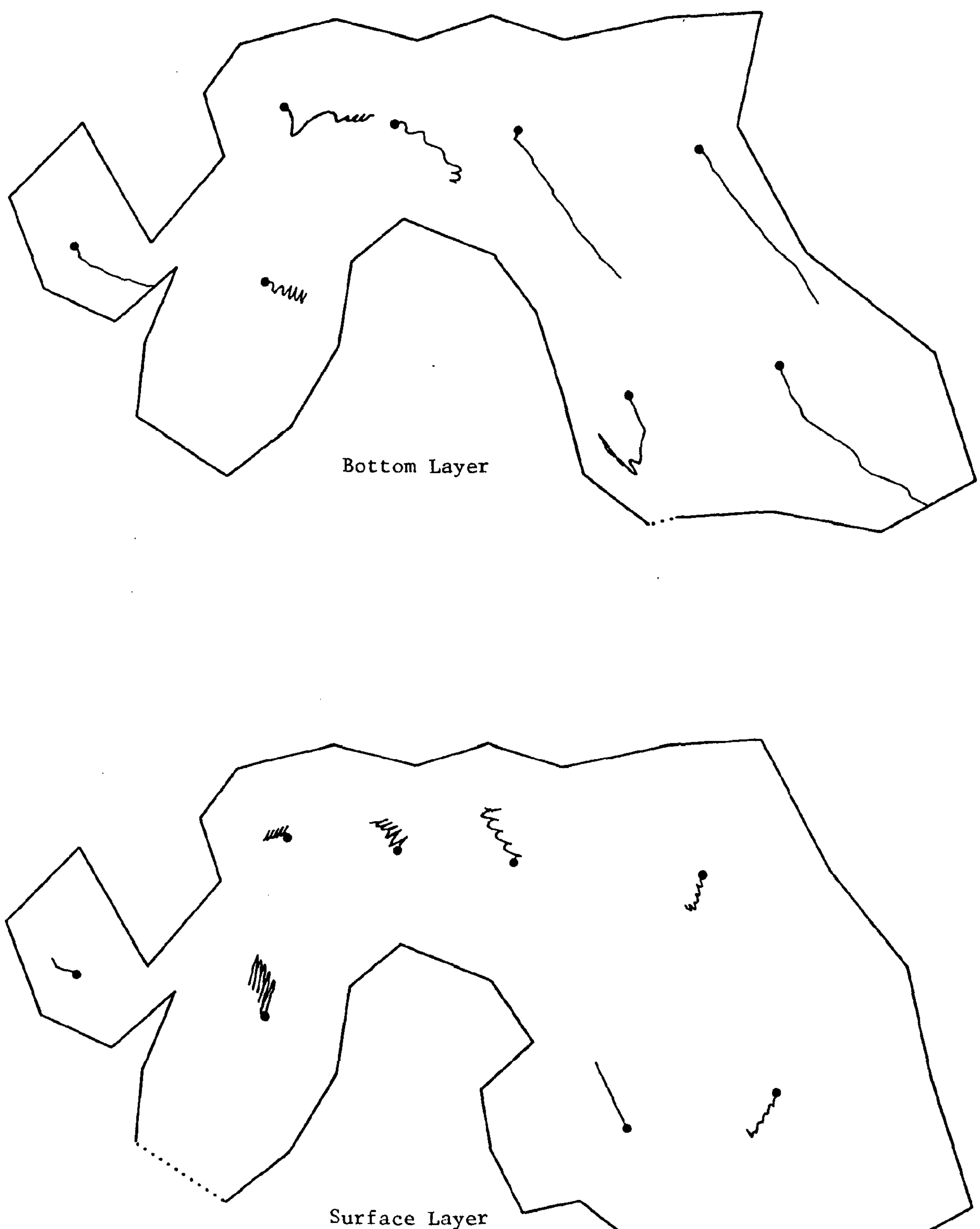



Fig. 8.4. Predicted particle trajectories for tide with SW wind.

to compare these results with those obtained by running the model over a longer period.

The particle trajectories tend to follow the wind cirection, however, the velocity is somewhat smaller than those obtained with the drogues. This is possibly due to the oversimplification committed in the model in assuming the surface layer to be vertically homogeneous. To resolve the near surface wind driven currents it appears that at least a 3-layer model would be necessary.

### 8.3 Northerly Wind

Strong winds out of the north persist during part of the winter months. During this period the stratification tends to break down because minimal freshwater inflow arrives to the Bay. The two layer model is therefore not applicable to describe the currents under these conditions, however, it may provide some information on the mechanisms instigating the destratification process.

A wind of 20 kn from the north is applied in the model, which is again started from "cold". The tides are included as previously described.

The computed velocity fields are shown in Figs. 8.5a to 8.5e. Significant differences are found in both layers compared to the pure tidal situation, which is particularly evident in the particle trajectories shown in Fig. 8.6. Due to the wind stress the surface adjusts with an upward slope in the downwind direction as the water is piled up against the southern boundary. This surface slope

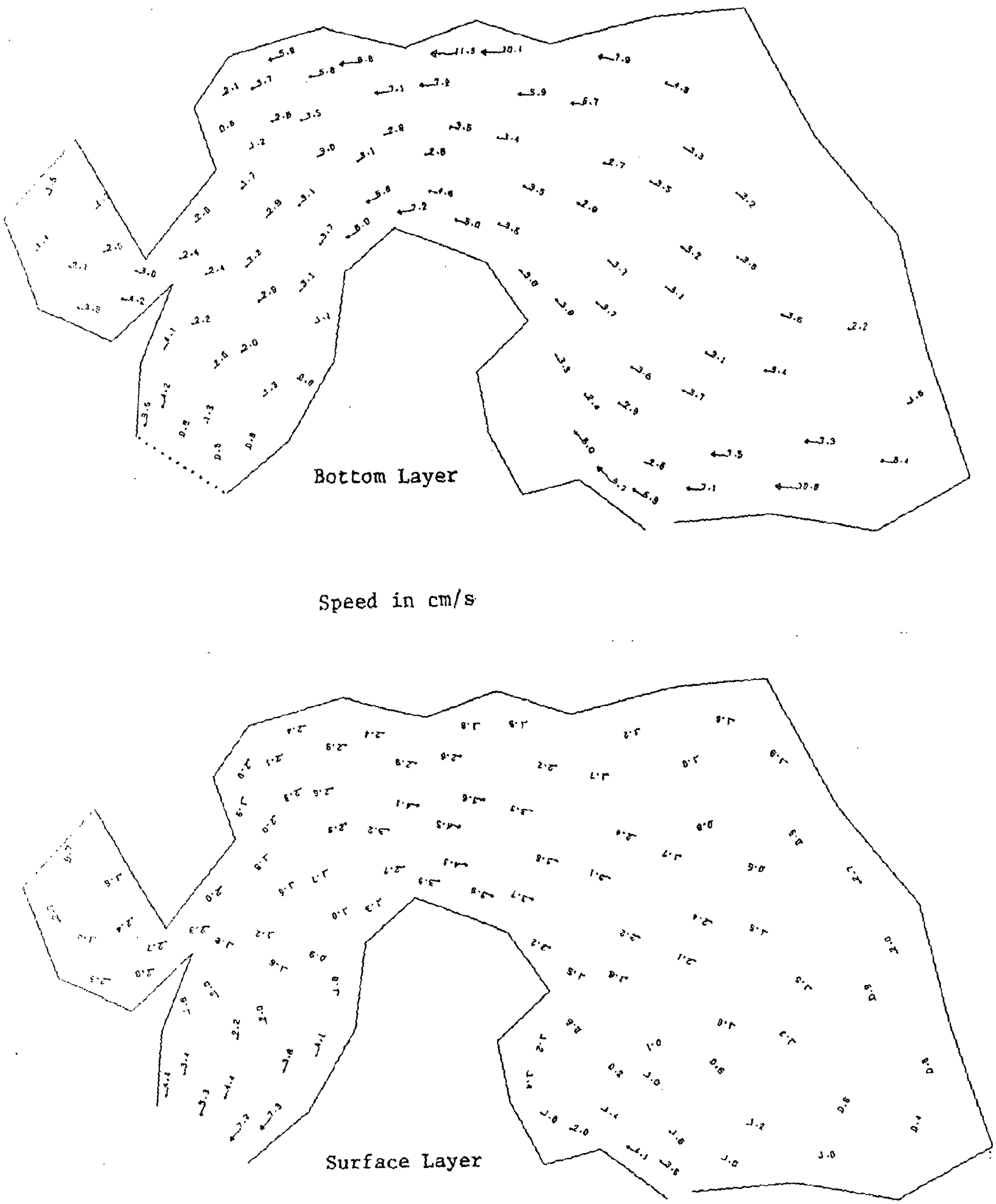



Fig. 8.5a. Predicted currents in Cartagena Bay. Tide and N wind. Time = LW + 9000 sec.

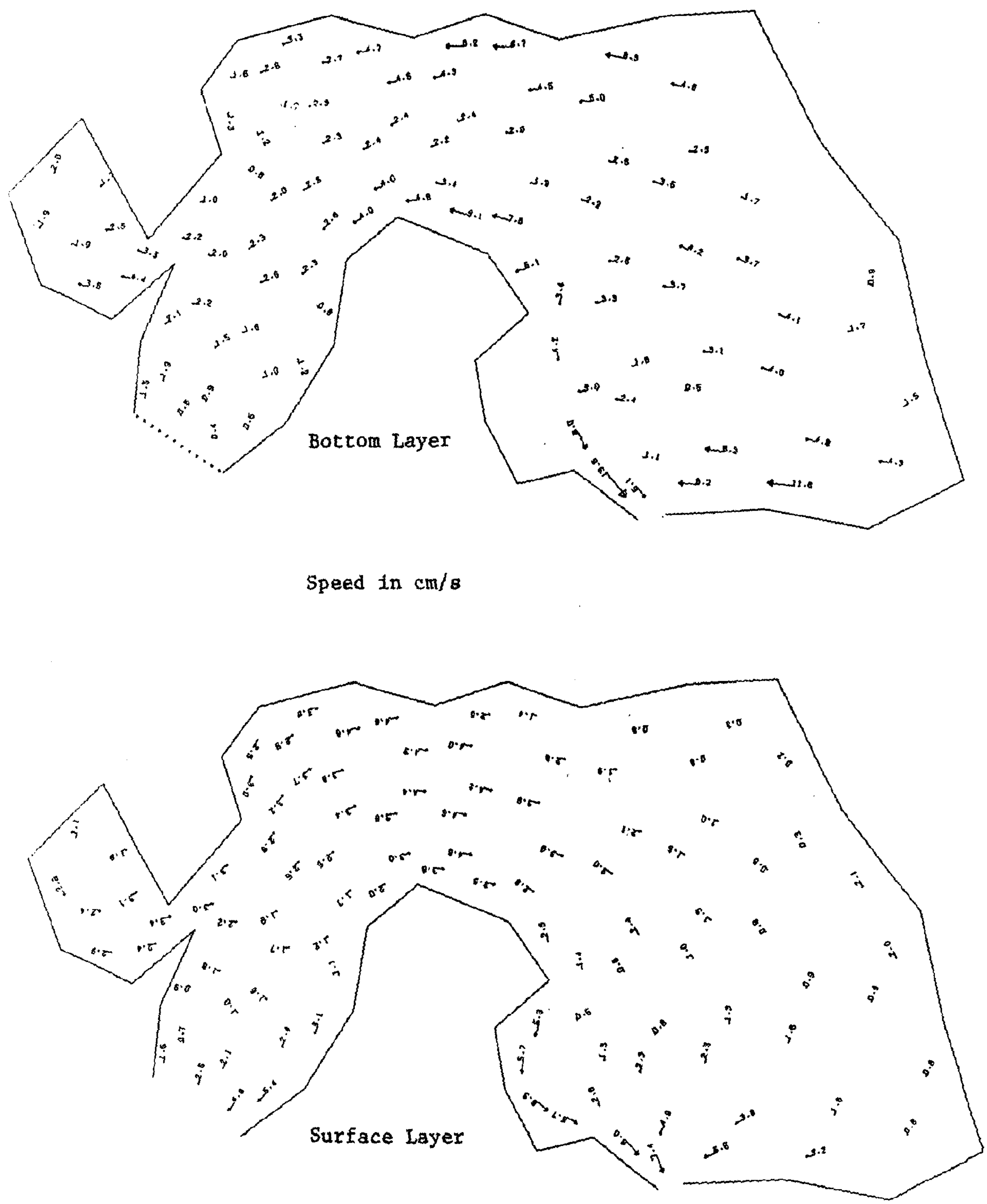



Fig. 8.5b. Predicted currents in Cartagena Bay. Tide and N wind.
Time = LW + 18000 sec.

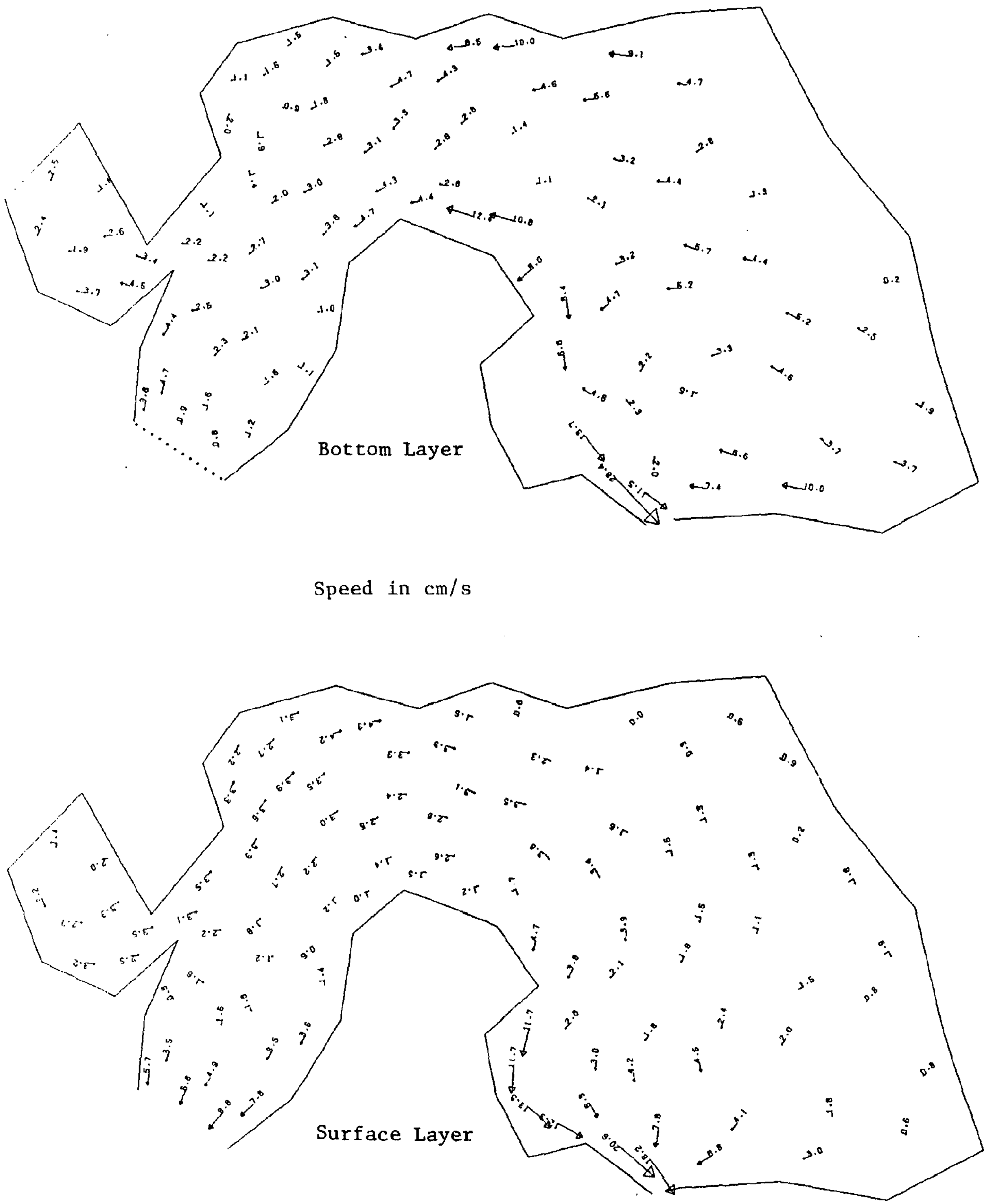



Fig. 8.5c. Predicted currents in Cartagena Bay. Tide and N wind.
Time = LW + 27000 sec.

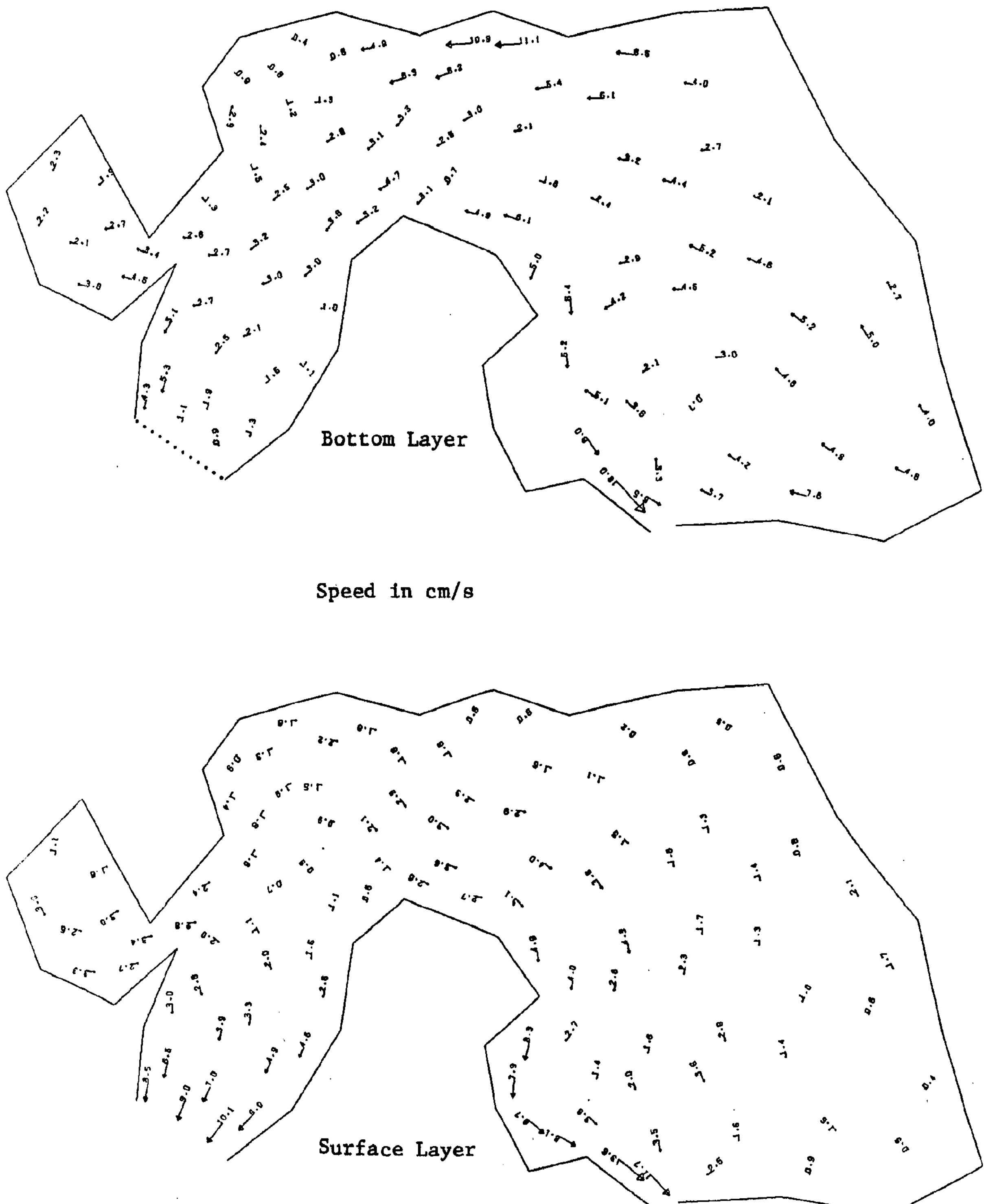



Fig. 8.5d. Predicted currents in Cartagena Bay. Tide and N wind.
Time = LW + 36000 sec.

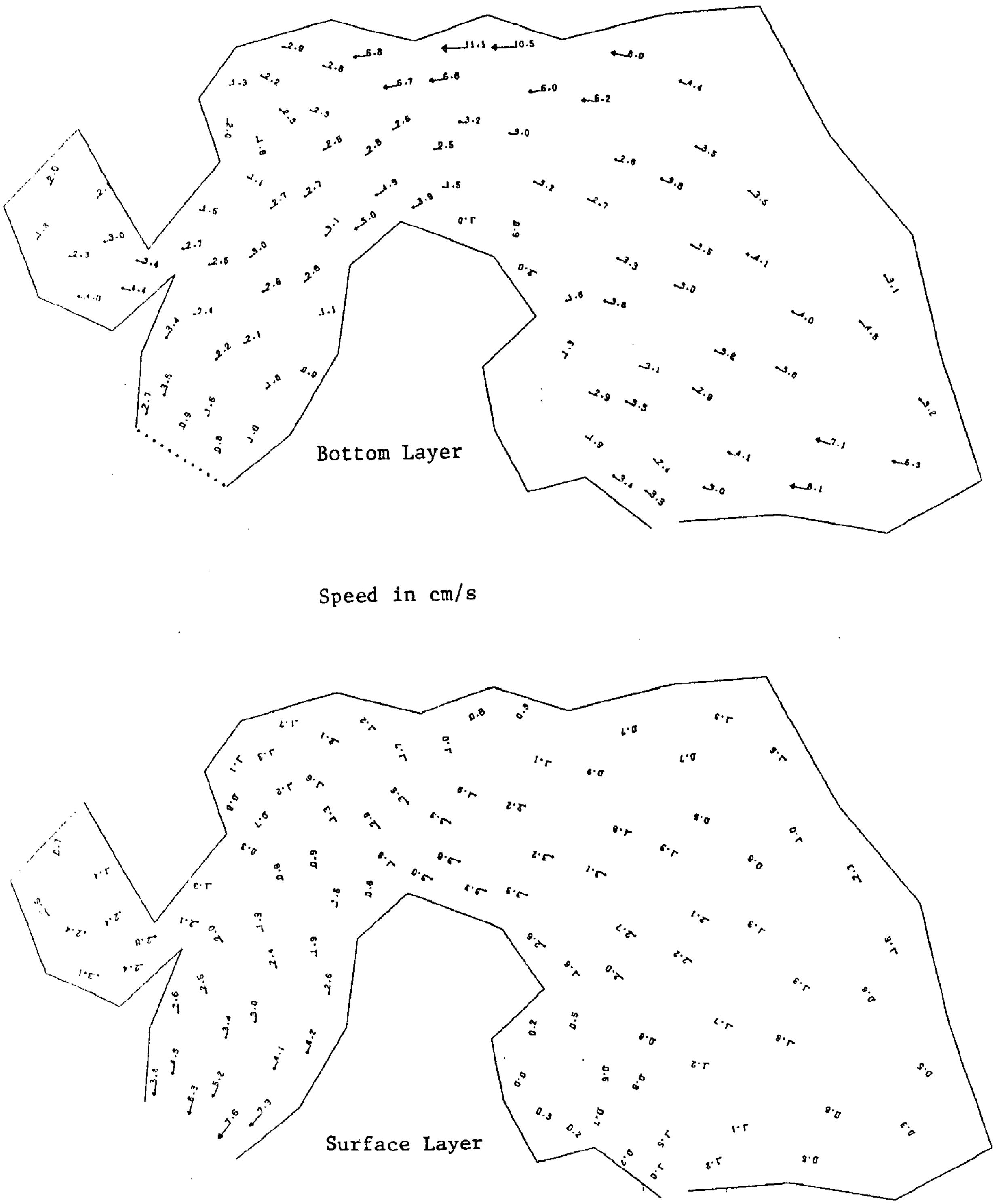



Fig. 8.5e. Predicted currents in Cartagena Bay. Tide and N wind.
Time = LW + 45000 sec.

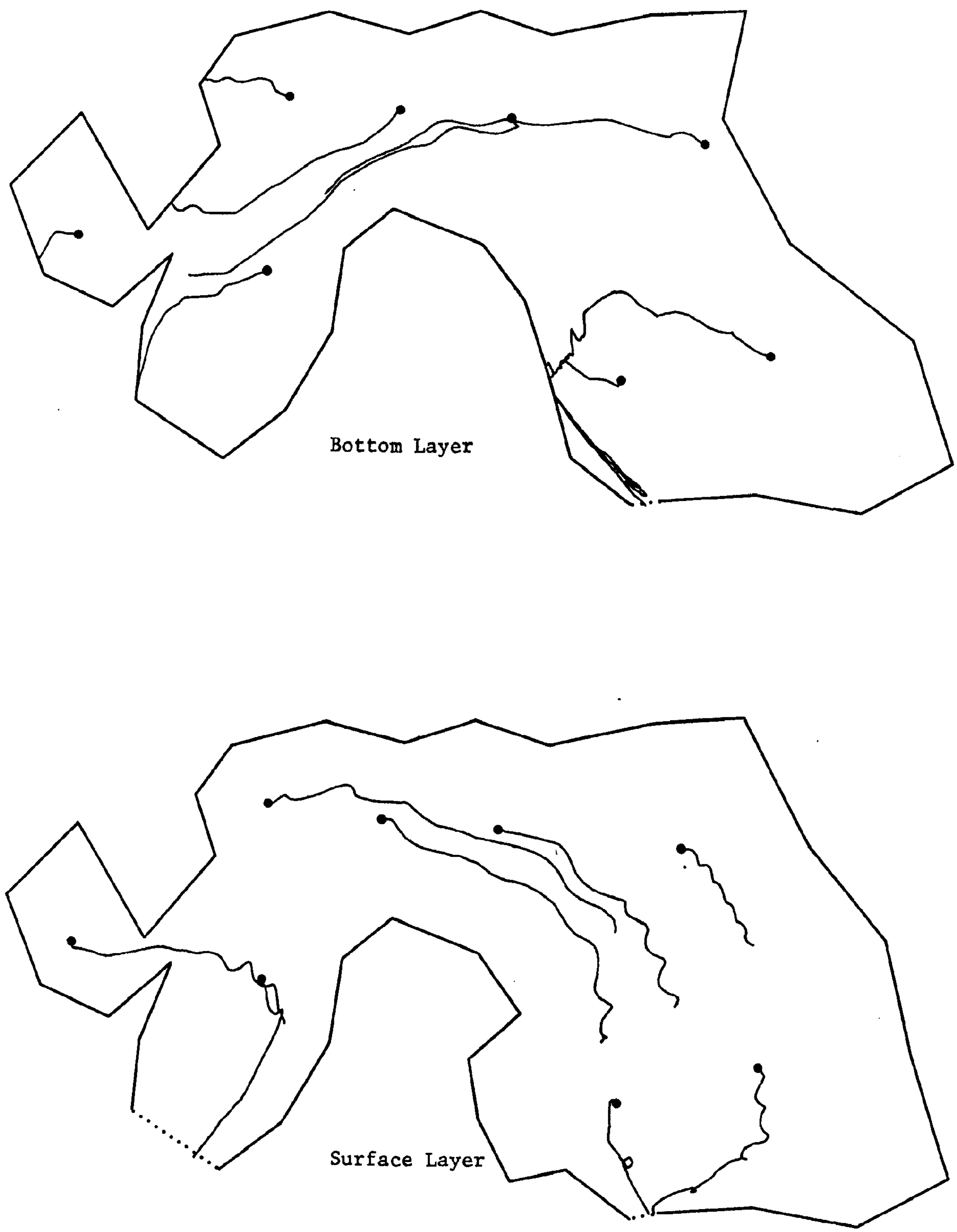



Fig. 8.6. Predicted particle trajectories for tide with N. wind.

is accompanied by the usual opposite interface slope as dictated by simple hydrostatics. When using an interfacial shear coefficient $C_1 = 0.003$ the interface reached the surface at the northern end of the Bay after approximately 50000 sec, and the simulation had to be stopped. By increasing $C_1$ to 0.01 the top layer depth in the north is about 2 m after 60000 sec and approximately 8 m in the southernmost part of the Bay. The velocity fields shown are for $C_1 = 0.01$, which is a very large almost unrealistic value. As previously mentioned the main objective of making this simulation is to learn more about the mixing mechanism due to wind rather than to obtain realistic current fields. For the latter purpose a different, perhaps unstratified model should be used.

The most evident destratification mechanism seems to be the elevation of the interface in the northern part of the Bay which then allows exchange between the ocean at Boca Grande and more importantly allows the wind to directly affect what was previously the bottom layer. It is quite likely that breaking internal waves also are generated in this situation leading to further mixing near the shores of the Bay.

These briefly outlined phenomena have not yet been verified by field observations and are only considered as possible working hypotheses at present.

## 9. DISCUSSION

Although the results obtained during this project are somewhat sketchy due to lack of sufficient current observations it is possible to perform a preliminary evaluation of existing and hypothetical scenarios. Two examples are considered in the following.

It has been shown that the freshwater inflow from Canal del Dique plays an important role in the stratification and flow patterns of the Bay. There is considerable evidence that the stratification causes minimal exchange to take place in the bottom layer of water stretching from 6-10 m below surface and down. This evidence consists mainly in direct current observations, model results and measurements of dissolved oxygen. On the other hand a net flow is generated in the surface layer due to the significant influx from the Canal, and this residual flow helps flushing in the upper water column of the Bay. With this background it is interesting to consider various alternatives for the future management of the canal. For example proposals have been formulated to dredge the canal to a greater depth in order to allow more shipping traffic. This in turn would probably result in an increase in the volume of water discharged by the Canal and therefore an even more distinct stratification in the Bay. Consequently, it is possible that the present destratification that occurs in the winter month and which provides some reprieve in terms of mixing and increased DO near the bottom would not occur or would be of shorter duration.

A natural question is then, what would an optimal discharge from the Canal be? A simple answer can of course not be offered, however experience in other places indicate that a partially mixed structure is desirable in terms of flushing and diversity of environmental conditions. Whether this is achievable without significant compromises in other areas seems to be a challenging subject for further research.

The sewage outfall of Cartagena which is presently located in the northern part of the Bay near the Manzanillo island is another structure deserving some consideration in the future. The raw sewage is probably a major contributor to the pollution load of the Bay and questions of treatment and/or relocation of the outfall will eventually be posed. Since our analysis shows that in all probability the flow in the Bay surface layer containing much of the suspended or dissolved sewage would carry the pollutants towards the open ocean through the Boca Grande entrance, it would seem attractive to relocate the outfall closer to Boca Grande or even to outside of the Bay. A careful analysis of the amount of treatment and the optimal point of discharge for the city in the coming year is within the realm of the possible with the information and models developed in this project.

## 10. CONCLUSION

Perhaps the most severe limitation to the efforts of the hydrodynamic investigations of Cartagena Bay has been the lack of a Colombian counterpart who was qualified and had time to take an active role in the data analysis and modeling effort. In spite of this, a number of Colombian individuals have been involved and trained in the design and actual process of data collection for a baseline study of the Bay.

The collected data already yields a reasonable picture of the seasonal variations in flow and mixing characteristics.

Progress towards describing the short term and smaller scale hydrodynamics has been made with the development of a twolayer numerical model for the Bay. Additional field work is needed to calibrate and verify this model. In particular more data on current velocities and on Canal del Dique discharges are needed.

The major highlights of our findings are that during the part of the year when the Bay is stratified there is a net flux of water out through the Boca Grande entrance. Estimates of flushing times due to tidal flow in the surface layer made from salinity data and using the model both result in approximately 10 days. Flushing in the bottom layer in this period is very slow because of the barrier at Boca Grande and the reduced vertical mixing.

During the winter months when the stratification breaks down fairly rapid exchange is expected due to the strong northerly winds and enhanced mixing.

Both the small amount of current data that has been analyzed and the model indicate that internal waves exist when the Bay is stratified. These waves seem to have periods between 2-15 hrs and cause significant currents of up to 5-10 cm/s. Thus they may contribute to horizontal mixing and vertical mixing if the waves break.

The typical summer winds from SW can induce significant flows and exchange, especially in the bottom layer. The prime driving mechanism in this process is the setup in the surface as the surface water is piled up against a shoreline and the subsequent barotropic tilting of the interface.

The strong northerly trade winds during winter may trigger the destratification process by inducing excessive tilt in the interface. However, the reduced inflow from Canal del Dique definitely also plays an important role. When the stratification in the Bay has been broken down, the trade winds cause significant horizontal and vertical mixing and exchange. This is also corroborated by the analysis of water quality parameters and benthic communities.

The stratification found in the Bay is overwhelmingly dominated by salinity variations. The temperature varies only little and ranges between 27 to 31°C over a year. The prime source of freshwater is the Canal del Dique, which reaches up to 200 $m^3/s$ at peak discharge periods. An interesting phenomenon for which considerable circumstantial evidence has been found is the possible sinking of the canal discharge due to its heavy sediment load.

ACKNOWLEDGEMENTS

A number of people from the Center for Oceanographic and Hydrographic Investigation (CIOH) in Cartagena contributed in data collection and analysis. Also the facilities of CIOH have been gracefully put to our disposition. The counterparts on the hydrodynamics have been in succession Tns. Diaz, LaTorre, Capt. Steer and Tn. Alvarado. Chief of the scientific unit at CIOH, Mr. R. Parra also made valuable contribution to the outcome of the project. Finally, Tn. Kaleda and Medina also of CIOH deserve much appreciation for help with translation and the many problems that arose throughout our joint venture.

From University of Miami Drs. Corcoran and Williams and Mr. M. Brown helped provide many good moments and stimulation through discussion of field work and results.

Finally, appreciation is given to CCO and especially the International Sea Grant Program which supported our efforts under Grant No. 04-8-M01-166.

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# APPENDIX A

## Program for Salinity from Conductivity and Temperature

```
JDW*COLUMBIA(1).CTTOS ELT CREATED ON 5 JUN 81 AT 10:56:24
              SUBROUTINE CTTOS(COND,TEMP,SAL)
              TAU=25.-TEMP
              CL=COND/3.
              A=0.145-0.002*TAU+0.0002*TAU**2
              B=-TAU*(88.3+0.55*TAU+0.0107*TAU**2)
              C=-12000.*(ALOG10(COND)-0.57627)
       20     FX=B+C+8820.*ALOG10(CL)+A*CL*TAU
              FPX=3873.9/CL+A*TAU
              CL1=CL-FX/FPX
              IF(ABS(CL1-CL) .LT. 0.01)GO TO 10
              CL=CL1
              GO TO 20
       10     CL=CL1
              SAL=1.8065*CL
              RETURN
              END
@PRT,S J.HARMANAL
```

# APPENDIX B

## Program for Harmonic Analysis of Tides

```
JOW*AR*FIL(1).HARMANAL ELT CREATED ON 5 OCT 78 AT 11:03:42
      C DATA AVAIABLE FROM 9/8 TO 12/03 1976
      C 15 MINUTE PERIOD OBSERVATOINS, TEN FREQUENCIES TO BE ANALYSED.
      C LEAST SQUARE METHOD
            DIMENSION AA(45,45),OBS(8200),FREQ(15),SIGMA(15),CI(15),SI(15),
           1 AMP(15),PH(15),X(240),TRIG(45)
            DIMENSION R(8200)
            DIMENSION T(8200),Y(8200)
            EQUIVALENCE(Y(1),OBS(1))
            CALL PLOTS(30.0,10.5,2)
            CALL FACTOR(.5)
            CALL PLOT(0.0,0.0,-3)
        142 READ(5,1011) NMFREQ,NMOBS
       1011 FORMAT(2I10)
            N=NMOBS
            IF(NMFREQ .LT. 0) GO TO 555
            T(1)=0.
            R(1)=0.
            WRITE(6,1002) NMFREQ,NMOBS
       1002 FORMAT(1H1,5X,'NMFREQ =',I10,5X,'NMOBS =',I10)
            READ(5,1003) (FREQ(I),I=1,NMFREQ)
       1003 FORMAT(8F10.7)
            WRITE(6,1004) (FREQ(I),I=1,NMFREQ)
       1004 FORMAT(1H0,1X,'FREQUENCIES DEGREES/HOUR',10F10.5)
            READ(5,1007) STRTIM,DELTIM
       1007 FORMAT(F10.0,F10.0)
             DEFINE FILE 12(1,NMOBS,U,TR)
             DEFINE FILE 11(1,NMOBS,U,TY)
             READ (11'1) (Y(I),I=1,NMOBS)
      C      READ(5,1017)NSKIP,NDAT,NDAY
      C 1017 FORMAT(3I10)
      C      IF(NSKIP .EQ. 0)GO TO 277
      C      DO 3 K=1,NSKIP
      C      DO 1 I=1,17
      C      READ(5,2)
      C 2     FORMAT(I1)
      C 1    CONTINUE
      C 3    CONTINUE
      C 277  DO 312 I=1,NDAY
      C      READ(5,1001)(X(J),J=1,240)
      C 1001 FORMAT(/,(5X,15F5.2))
      C      I1=(I-1)*NDAT+1
      C      I2=I*NDAT
      C       IF(I2 .GT. N)I2=N
      C      DO 122 J=I1,I2
      C      J1=J-I1+1
      C      Y(J)=Y(J1)
      C      YSUM=YSUM+Y(J)
      C 122  CONTINUE
      C 310  CONTINUE
      C      READ(5,1013)DUMMY
      C1013 FORMAT(A1)
      C      READ(5,1015)(OBS(I), I=1,NMOBS)
      C1015 FORMAT(14F5.2)
            TOPI=2.*3.1415927
            PI=3.1415927
            SUM=0.
            NF2=2*NMFREQ
            NF21=NF2+1
            NF22=NF2+2
            DO 20 I=1,NF21
            DO 30 J=1,NF22
            AA(I,J)=0.
         30 CONTINUE
         20 CONTINUE
            TIME=STRTIM
            TRIG(1)=1.
            DO 40 I=1,NMOBS
            DO 50 J=2,NF2,2
            JH=J/2
            PER=360./FREQ(JH)
            SIGMA(JH)=TOPI/PER
            ARC=SIGMA(JH)*TIME
            J1=J+1
            TRIG(J)=COS(ARC)
            TRIG(J1)=SIN(ARC)
         50 CONTINUE
            TIME=TIME+DELTIM
            TRIG(NF22)=OBS(I)
```

```
      DO 60 I1=1,NF21
      DO 70 J1=I1,NF22
      AA(I1,J1)=AA(I1,J1)+TRIG(I1)*TRIG(J1)
      AA(J1,I1)=AA(I1,J1)
70    CONTINUE
60    CONTINUE
40    CONTINUE
      ANMOBS=NMOBS
      CALL VARSER(OBS,NMOBS,AMEAN,VAR)  SUBROUTINE COMPUTES MEAN AND VARIANCE OF OBS
      WRITE(6,1012)AMEAN
1012  FORMAT(1H ,'  MEAN OF SERIES =',E15.6)
      DO 320 I=1,NF21
      DIAG=AA(I,I)
      AA(I,I)=1.
      DO 130 J=1,NF22
      IF (J .NE. I) AA(I,J)=AA(I,J)/DIAG
130   CONTINUE
320   CONTINUE
      EPS=1.E-20
      DETER=SIMUL(NF21,AA,X,EPS,-1,45) FUNCTION INVERTS MATRIX AA AND RETURNS DETERMINANT VALUE
      IF(ABS(DETER) .GT. 1.E-10) GO TO 80
      WRITE(6,1008) DETER
1008  FORMAT(1H0,5X,'SINGULAR OR ILL-CONDITIONED MATRIX, DETER ='
     1  E15.6)
      STOP
80    DO 90 I=1,NF21
      X(I)=0.
      DO 100 J=1,NF21
      X(I)=X(I)+AA(I,J)*AA(J,NF22)
100   CONTINUE
90    CONTINUE
      WRITE(6,1012)X(1)
      DO 110 I=1,NMFREQ
      I2=I+2
      CI(I)=X(I2)
      SI(I)=X(I2+1)
      AMP(I)=SQRT(CI(I)**2+SI(I)**2)
      PH(I)=ATAN2(SI(I),CI(I))*180./3.14159
      WRITE(6,1010) FREQ(I),AMP(I),PH(I),CI(I),SI(I)
1010  FORMAT(1H0,5E15.6)
110   CONTINUE
      T(1)=STRTTM
      S=T(1)
      DO 7 J=1,NMOBS
      R(J)=0.0
      DO 6 I=1,NMFREQ
      R(J)=R(J)+AMP(I)*(COS((FREQ(I)*S-PH(I))*(3.14159/180.)))
6     CONTINUE
      R(J)=OBS(J)-R(J)-X(1)
      T(J+1)=T(J)+DELTIM
      S=T(J+1)
7     CONTINUE
      WRITE(10*1)(R(J), J=1,NMOBS)
      CALL VARSER(R,NMOBS,RMEAN,RVAR)
      WRITE(6,1014)VAR,RVAR
1014  FORMAT(1H ,'  VARIANCE OF ORIGINAL SERIES =',E15.6/
     1  1H ,'  VARIANCE OF RESIDUAL SERIES =',E15.6)
      CALL PLOT(0.0,0.0,3)
      T(NMOBS+1)=0.0
      T(NMOBS+2)=48.0
      TLENGT=(NMOBS*DELTIM+2.)/48.
      CALL AXIS(0.0,0.0,'TIME IN HOURS',-13,TLENGT,0.0,0.0,48.)
      CALL SCALE(R, 8.0,NMOBS,+1)
      CALL AXIS(0.0,0.0,'RESIDUAL IN FEET',16,8.,90.,R(NMOBS+1),
     * R(NMOBS+2))
      CALL LINE(T,R,NMOBS,1,0,0)
      CALL PLOT(0.0,0.0,999)
555   STOP
      END
```

```
JDW*COLUMBIA(1).FIELDATA ELT CREATED ON 25 NOV 81 AT 12:39:28
HTC: TEMPERATURE-CONDUCTIVITY-SALINITY
COL  4- 9: MONTH-DAY-YEAR
COL 10-13: TIME
COL 14-17: LATITUDE MINUTES AND SECONDS,  10 DEGREES UNDERSTOOD.
COL 18-21: LONGITUDE MINUTES AND SECONDS, 75 DEGREES UNDERSTOOD.
COL 22-23: TOTAL STATION DEPTH IN METERS
COL 24-25: STATION IDENTIFICATION
COL 26-28: BLANK
COL 29-31: DEPTH IN DECIMETERS
COL 32-34: TEMPERATURE, DEGREES C.
COL 35-37: CONDUCTIVITY, MMHO/CM
COL 38-40: SALINITY, PPT.
COL 41-43: DEPTH IN DECIMETERS
COL 44-46: TEMPERATURE, DEGREES C.
COL 47-49: CONDUCTIVITY, MMHO/CM
COL 50-52: SALINITY, PPT.
COL 53-55: DEPTH IN DECIMETERS
COL 56-58: TEMPERATURE, DEGREES C.
COL 59-61: CONDUCTIVITY, MMHO/CM
COL 62-64: SALINITY, PPT.
COL 65-67: DEPTH IN DECIMETERS
COL 68-70: TEMPERATURE, DEGREES C.
COL 71-73: CONDUCTIVITY, MMHO/CM
COL 74-76: SALINITY, PPT.
HTC050580090523303420  01     000290550   010290550   020285550   030285550
HTC050580090523303420  01     040280550   050280550   050280550   050280550
HTC050580091723003300  02     000290570   010290560   020290560   030285560
HTC050580091723003300  02     040285560   050280560   080270560   100270560
HTC050580091723003300  02     120270565   150268565   200265580   260260580
HTC050580093022203155  03     000290565   010290565   020287575   030287570
HTC050580093022203155  03     040285575   050285575   080285580   100285585
HTC050580093022203155  03     120280585   150270585   200265585   250265590
HTC050580095821203145  04     000295550   010295560   020292570   030290580
HTC050580095821203145  04     040290580   050287580   080285585   100280585
HTC050580095821203145  04     120273585   150268585   200265585   250265585
HTC050580101020203125  05     000295560   010295560   020295565   030290580
HTC050580101020203125  05     040285580   050280585   080280585   100278590
HTC050580101020203125  05     120275590   150274590   200265590   240265590
HTC050580102519203130  06     000300535   010295555   020295565   030288570
HTC050580102519203130  06     040285580   050283580   080280585   100277585
HTC050580102519203130  06     120270585   150270590   200265570   200265570
HTC050580103018103145  07     000305460   010300535   020305550   030300575
HTC050580103018103145  07     040295580   050285580   080282585   100275585
HTC050580103018103145  07     120270590   150268590   250265590   250265590
HTC050580105017303250  08     000300470   010295510   020290570   030290580
HTC050580105017303250  08     040285580   050285585   080280590   100275590
HTC050580105017303250  08     120273590   150270590   200265590   260265590
HTC050580110017203405  09     000300455   010295490   020290570   030290575
HTC050580110017203405  09     040285575   050285580   080280585   100274585
HTC050580110017203405  09     120270585   150270585   200265585   240265585
HTC050580110519153415  10     000300500   010297530   020290570   030287570
HTC050580110519153415  10     040285580   050285580   080280590   100275590
HTC050580110519153415  10     120270590   150265590   190265590   190265590
HTC050580111319253250  11     000300540   010300550   020295570   030290570
HTC050580111319253250  11     040290575   050285580   080275590   100270590
HTC050580111319253250  11     120270590   150267590   200265590   250265590
HTC050580112520153215  12     000300550   010297555   020295555   030285570
HTC050580112520153215  12     040285580   050285585   080280590   100275590
HTC050580112520153215  12     120270590   150267590   200265590   250265590
HTC062179080023303420  01     000291   342015290   365025290   367
HTC062179082323003300  02     000294   272010295   292030296   345050295   352
HTC062179082323003300  02     070293   359090284   364110284   366130283   366
HTC062179082323003300  02     150281   368210276   369170279   368190277   368
HTC062179082323003300  02     230275   369250274   369266275   369
HTC062179090022203155  03     000298   277010301   330030294   352050292   357
HTC062179090022203155  03     070288   360090284   363110283   364130282   366
HTC062179090022203155  03     150280   367210277   368230276   367255276   368
HTC062179090022203155  03     170278   368190278   367
HTC062179091521203145  04     000307   277020298   340040294   351060290   357
HTC062179091521203145  04     080286   361100284   363120283   365140282   365
HTC062179091521203145  04     160279   366180278   367200276   368220276   367
HTC062179091521203145  04     240276   367260275   367275277   366
HTC062179094520203125  05     000310   310020299   335040294   349060286   360
HTC062179094520203125  05     080285   363100284   364120283   367140283   366
HTC062179094520203125  05     160280   366180279   367222276   368200277   367
HTC062179100019203130  06     000312   293020298   339040293   350060291   353
HTC062179100019203130  06     080287   362100282   365120280   367140279   366
HTC062179100019203130  06     160279   367180277   367200276   365
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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 79 | HTC062179102018103145 | 07 | 000305 | 274010304 | 309030297 | 300050294 | 346 |
| 80 | HTC062179102018103145 | 07 | 070290 | 357090285 | 362110283 | 363130281 | 365 |
| 81 | HTC062179102018103145 | 07 | 150279 | 366170278 | 366190276 | 367210276 | 366 |
| 82 | HTC062179102018103145 | 07 | 235276 | 366 | | | |
| 83 | HTC062179110317303250 | 08 | 000316 | 291010304 | 310020303 | 311030301 | 329 |
| 84 | HTC062179110517303250 | 08 | 050295 | 353070290 | 360090287 | 363110284 | 367 |
| 85 | HTC062179110517303250 | 08 | 130281 | 368150281 | 368170280 | 368190280 | 368 |
| 86 | HTC062179110517303250 | 08 | 210278 | 369230278 | 370255276 | 368 | |
| 87 | HTC062179112517203405 | 09 | 000311 | 276010303 | 293030298 | 343050293 | 352 |
| 88 | HTC062179112517203405 | 09 | 070289 | 358090286 | 361110284 | 364130281 | 365 |
| 89 | HTC062179112517203405 | 09 | 150280 | 366170279 | 366190279 | 366210278 | 366 |
| 90 | HTC062179112517203405 | 09 | 230277 | 367245277 | 367 | | |
| 91 | HTC062179114519153415 | 10 | 000323 | 222010308 | 260020296 | 345030295 | 351 |
| 92 | HTC062179114519153415 | 10 | 040293 | 354052291 | 359 | | |
| 93 | HTC062179120019253250 | 11 | 000327 | 221010296 | 336020292 | 354040290 | 357 |
| 94 | HTC062179120019253250 | 11 | 060289 | 359080285 | 362100284 | 363120283 | 364 |
| 95 | HTC062179120019253250 | 11 | 140280 | 367160280 | 366180278 | 367200276 | 367 |
| 96 | HTC062179120019253250 | 11 | 220276 | 367253276 | 368 | | |
| 97 | HTC062179122020153215 | 12 | 000319 | 248010301 | 285020298 | 337040293 | 352 |
| 98 | HTC062179122020153215 | 12 | 060291 | 355080287 | 361100285 | 363120284 | 364 |
| 99 | HTC062179122020153215 | 12 | 140280 | 365160279 | 366180278 | 366200278 | 366 |
| 100 | HTC062179122020153215 | 12 | 220276 | 368245275 | 367 | | |
| 101 | HTC101679 90023303420 | 1 | 0301 | 282 10299 | 323 20294 | 344 30291 | 346 |
| 102 | HTC101679 90023303420 | 1 | 40291 | 348 50291 | 348 60291 | 348 70290 | 350 |
| 103 | HTC101679 91023003300 | 2 | 0303 | 279 20307 | 296 40302 | 338 60303 | 347 |
| 104 | HTC101679 91023003300 | 2 | 80296 | 360100293 | 363120291 | 366140288 | 368 |
| 105 | HTC101679 91023003300 | 2 | 160285 | 369180284 | 370200284 | 370220283 | 370 |
| 106 | HTC101679 91023003300 | 2 | 240283 | 370260281 | 370280282 | 370 | |
| 107 | HTC101679 92922203155 | 3 | 0302 | 278 20304 | 289 40302 | 333 60302 | 341 |
| 108 | HTC101679 92922203155 | 3 | 80299 | 352110292 | 361140290 | 367170286 | 369 |
| 109 | HTC101679 92922203155 | 3 | 200285 | 369230284 | 369260283 | 370 | |
| 110 | HTC101679 94421203145 | 4 | 0299 | 275 30303 | 317 50301 | 339 70300 | 347 |
| 111 | HTC101679 94421203145 | 4 | 90297 | 355110295 | 359130291 | 364160288 | 366 |
| 112 | HTC101679 94421203145 | 4 | 190287 | 368220283 | 369250283 | 369280286 | 353 |
| 113 | HTC101679100220203125 | 5 | 0302 | 259 20304 | 323 40302 | 327 60302 | 340 |
| 114 | HTC101679100220203125 | 5 | 90298 | 355120297 | 359150292 | 367180289 | 368 |
| 115 | HTC101679100220203125 | 5 | 210286 | 370240284 | 367 | | |
| 116 | HTC101679101319203130 | 6 | 0306 | 221 20302 | 327 40301 | 328 60300 | 339 |
| 117 | HTC101679101319203130 | 6 | 80300 | 346100298 | 354130294 | 363160288 | 368 |
| 118 | HTC101679101319203130 | 6 | 190287 | 370220285 | 359 | | |
| 119 | HTC101679103218103145 | 7 | 0305 | 224 20301 | 329 40299 | 332 60299 | 337 |
| 120 | HTC101679103218103145 | 7 | 90298 | 347120293 | 362150291 | 365180287 | 368 |
| 121 | HTC101679103218103145 | 7 | 210285 | 369240283 | 369 | | |
| 122 | HTC101679105017303250 | 8 | 0304 | 289 10304 | 313 30305 | 325 50301 | 331 |
| 123 | HTC101679105017303250 | 8 | 70300 | 337 90298 | 351120291 | 362150289 | 365 |
| 124 | HTC101679105017303250 | 8 | 180286 | 367210283 | 368240283 | 368270283 | 369 |
| 125 | HTC101679105017303250 | 8 | 300283 | 368 | | | |
| 126 | HTC101679110817203405 | 9 | 0303 | 288 20306 | 317 40303 | 331 60302 | 339 |
| 127 | HTC101679110817203405 | 9 | 80300 | 348110293 | 366140290 | 367 | |
| 128 | HTC101679112519153415 | 10 | 0303 | 272 20300 | 293 40297 | 332 60294 | 345 |
| 129 | HTC101679112519153415 | 10 | 90292 | 359120292 | 360150291 | 359 | |
| 130 | HTC101679113919253250 | 11 | 0306 | 271 20301 | 277 40299 | 327 60300 | 346 |
| 131 | HTC101679113919253250 | 11 | 80298 | 355100295 | 360130291 | 364160289 | 367 |
| 132 | HTC101679113919253250 | 11 | 190287 | 369220285 | 369250283 | 369280283 | 369 |
| 133 | HTC101679114520153215 | 12 | 0308 | 248 10304 | 263 30301 | 327 50300 | 335 |
| 134 | HTC101679114520153215 | 12 | 70300 | 345100297 | 354130294 | 361160290 | 367 |
| 135 | HTC101679114520153215 | 12 | 190288 | 367240284 | 369290283 | 369 | |
| 136 | HTC102880 85923303420 | 1 | 0299 | 288 10299 | 326 20297 | 339 30298 | 347 |
| 137 | HTC102880 85923303420 | 1 | 40298 | 347 50295 | 351 | | |
| 138 | HTC102880 91123003300 | 2 | 0300 | 283 10304 | 325 20303 | 331 30302 | 337 |
| 139 | HTC102880 91123003300 | 2 | 40300 | 340 50299 | 346 70297 | 347 90294 | 356 |
| 140 | HTC102880 91123003300 | 2 | 110293 | 359130293 | 361150290 | 361200287 | 365 |
| 141 | HTC102880 91123003300 | 2 | 250282 | 366270284 | 367 | | |
| 142 | HTC102880 92522203155 | 3 | 0296 | 274 10299 | 281 20300 | 285 30302 | 329 |
| 143 | HTC102880 92522203155 | 3 | 40302 | 336 50298 | 341 70296 | 347 90294 | 350 |
| 144 | HTC102880 92522203155 | 3 | 110291 | 355130290 | 357150290 | 358200286 | 360 |
| 145 | HTC102880 92522203155 | 3 | 250282 | 362 | | | |
| 146 | HTC102880 94021203145 | 4 | 0299 | 267 10295 | 281 20302 | 331 30299 | 341 |
| 147 | HTC102880 94021203145 | 4 | 40297 | 347 50297 | 351 70292 | 352 90293 | 354 |
| 148 | HTC102880 94021203145 | 4 | 110289 | 358130289 | 359150287 | 361200284 | 363 |
| 149 | HTC102880 94021203145 | 4 | 250281 | 365270283 | 367 | | |
| 150 | HTC102880 95720203125 | 5 | 0305 | 281 10306 | 297 20303 | 317 30301 | 326 |
| 151 | HTC102880 95720203125 | 5 | 40299 | 334 50297 | 338 70294 | 340 90293 | 344 |
| 152 | HTC102880 95720203125 | 5 | 110290 | 349130288 | 348150288 | 351200283 | 355 |
| 153 | HTC102880 95720203125 | 5 | 250281 | 358 | | | |
| 154 | HTC102880100919203130 | 6 | 0312 | 283 10306 | 311 20301 | 322 30301 | 330 |
| 155 | HTC102880100919203130 | 6 | 40300 | 333 50298 | 334 70296 | 337 90293 | 342 |
| 156 | HTC102880100919203130 | 6 | 110291 | 347130288 | 350150286 | 352200284 | 355 |
| 157 | HTC102880101918103145 | 7 | 0303 | 302 10302 | 304 20302 | 312 30299 | 330 |

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159   HTC10288010191A103145   7    110290  348130290  349150288  350200284  355
160   HTC102880103017303250   8      0300  284 10302  305 20301  319 30298  326
161   HTC102880103017303250   8     40297  333 50297  334 70294  340 90291  345
162   HTC102880103017303250   8    110289  347130289  347150288  350200286  352
163   HTC102880103017303250   8    240282  356
164   HTC102880104417503405   9      0297  250 10300  283 20303  311 30300  326
165   HTC102880104417503405   9     40299  332 50298  331 70295  337 90293  341
166   HTC102880104417503405   9    110290  343130288  345150288  347200283  353
167   HTC102880104417203405   9    260283  353
168   HTC102880105619153415  10      0302  244 10300  267 20296  318 30296  334
169   HTC102880105619153415  10     40296  335 50296  336 70292  342 90291  345
170   HTC102880105619153415  10    110289  347130288  347150286  349200282  355
171   HTC102880105619153415  10    250281  354300280  355
172   HTC102880111119553250  11      0309  275 10302  289 20302  302 30300  340
173   HTC102880111119553250  11     40296  350 50296  351 70294  354 90292  360
174   HTC102880111119553250  11    110291  363130289  363150288  363200282  369
175   HTC102880111119253250  11    250281  367300282  367
176   HTC102880112720153215  12      0315  263 10307  282 20303  308 30299  335
177   HTC102880112720153215  12     40298  342 50296  344 70294  349 90293  349
178   HTC102880112720153215  12    110291  353130289  356150288  358200282  363
179   HTC102880112720153215  12    250282  363290281  363
180   HTC102880141023303420   1      0308  297 10304  340 20303  345 30301  350
181   HTC102880141023303420   1     40298  353 50298  356
182   HTC102880142023003300   2      0312  297 10310  314 20306  335 30303  345
183   HTC102880142023003300   2     40299  350 50301  352 70297  358 90295  361
184   HTC102880142023003300   2    110292  361130293  365150291  367200287  369
185   HTC102880142023003300   2    250284  370270284  374
186   HTC102880143122503155   3      0310  292 10305  298 20306  323 30304  340
187   HTC102880143122503155   3     40298  351 50298  351 70297  353 90296  358
188   HTC102880143122503155   3    110291  360130290  362150291  365200288  368
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190   HTC102880143821503145   4      0314  279 10311  281 20306  331 30302  342
191   HTC102880143821503145   4     40299  346 50297  352 70296  356 90294  359
192   HTC102880143821503145   4    110293  361130290  363150289  367200285  372
193   HTC102880143821503145   4    250283  372270283  372
194   HTC102880145020503125   5      0312  287 10313  289 20310  297 30307  328
195   HTC102880145020503125   5     40301  347 50297  349 70296  352 90293  357
196   HTC102880145020503125   5    110293  359130291  363150289  364200284  370
197   HTC102880145020503125   5    250283  371
198   HTC102880150019503130   6      0311  296 10311  298 20311  301 30310  314
199   HTC102880150019503130   6     40303  328 50302  342 70299  349 90297  356
200   HTC102880150019203130   6    110291  363130291  365150289  364200287  370
201   HTC102880151218103145   7      0309  281 10307  296 20306  302 30302  338
202   HTC102880151219103145   7     40302  345 50300  350 70296  355 90290  362
203   HTC102880151218103145   7    110288  365130288  367150288  369200287  371
204   HTC102880152517303250   8      0308  288 10308  290 20307  297 30301  340
205   HTC102880152517303250   8     40298  349 50296  353 70293  360 90290  363
206   HTC102880152517303250   8    110290  363130289  366150288  368200285  371
207   HTC102880152517303250   8    240283  372
208   HTC102880154017503405   9      0307  284 10308  284 20308  312 30300  333
209   HTC102880154017503405   9     40298  337 50297  337 70294  343 90293  347
210   HTC102880154017503405   9    110292  350130290  351150290  352200286  354
211   HTC102880154017203405   9    250283  364
212   HTC102880155519153415  10      0304  311 10303  311 20303  334 30298  334
213   HTC102880155519153415  10     40300  335 50299  337 70295  341 90293  344
214   HTC102880155519153415  10    110293  345130292  348150288  352200285  354
215   HTC102880155519153415  10    250283  358300281  358
216   HTC102880160819553250  11      0309  260 10307  287 20301  322 30297  328
217   HTC102880160819553250  11     40296  336 50295  339 70295  341 90292  344
218   HTC102880160819553250  11    110291  347130292  346150290  348200288  351
219   HTC102880160819253250  11    250283  356300283  358
220   HTC102880162020153215  12      0309  272 10309  277 20305  315 30301  330
221   HTC102880162020153215  12     40299  335 50297  338 70295  341 90295  343
222   HTC102880162020153215  12    110292  346130292  347150291  350200284  358
223   HTC102880162020153215  12    250282  359290283  359
224   HTC020981142123303420  01  010280584364050275586370100271586371150271585371
225   HTC020981143523003300  02  010281585365050278585366100276585367150271586373
226   HTC020981143523003300  02  200270585375270263584371
227   HTC020981145022503155  03  010283578358050277583366100273584369150271585369
228   HTC020981145022503155  03  200271584370260269584371
229   HTC020981150021503145  04  010287576353050275579363100273586370150271587370
230   HTC020981150021503145  04  200270586372250270586373280268585373
231   HTC020981151520503125  05  010288571350050276578363100273585369150273585370
232   HTC020981151520503125  05  200271584370260270585372
233   HTC020981152419503130  06  010289571350050280574359100274582365150272586371
234   HTC020981152419503130  06  220270584368
235   HTC020981153118103145  07  010289568348050270573358100274581365150270587371
236   HTC020981153118103145  07  200271586370240270586371
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257   HTC020981154017303250   08   010285566349050280574358100275581365150273586370
258   HTC020981154017303250   08   200271586370270270586371
239   HTC020981155017203405   09   0102885623440502785753601002755793631502/2587371
240   HTC020981155017203405   09   210271587372
241   HTC020981160019153415   10   010283563348050277573358100272586370150271586370
242   HTC020981160019153415   10   200271586370270270585371
243   HTC020981160919253250   11   010282570353050274575358100271586370150271585370
244   HTC020981160919253250   11   200271585371270270583371
245   HTC020981161820153215   12   010280575358050274580364100272586370150272585371
246   HTC020981161820153215   12   200271585371250270585371280270585371
247   HTC021081131118133130   13   01029153232205027957835610027558636715027 3589   0
248   HTC021081131118133130   13   170273590372
249   HTC021081132018763125   14   010288573349050282579356100274584366150272589372
250   HTC021081132018763125   14   200272590373
251   HTC021081125918053152   15   010292535324050281576358100274587369150272590372
252   HTC021081125918053152   15   200273571360
253   HTC021081121117543230   16   010290557302050277585365100273591373180272591372
254   HTC021081122517363239   17   010293536323050278580361100274588369150273591373
255   HTC021081122517363239   17   200275592371230274533332
256   HTC021081120217293136   18   005303050023010300153084020291314181
257   HTC021081123517303250   08   010289566344050278579360100275582365150271590371
258   HTC021081123517303250   08   200272590371240279545339
259   HTC021081125018103245   07   0102905593400502805793611002755833661502735893 2
260   HTC021081125018103245   07   200271589371250271577364
261   HTU TURBIDITY
262   COL  4- 9: MONTH-DAY-YEAR
263   COL 10-13: TIME
264   COL 14-17: LATITUDE MINUTES AND SECONDS,   10 DEGREES UNDERSTOOD.
265   COL 18-21: LONGITUDE MINUTES AND SECONDS,  75 DEGREES UNDERSTOOD.
266   COL 22-23: TOTAL STATION DEPTH IN METERS
267   COL 24-25: STATION IDENTIFICATION
268   COL 26-28: TOTAL DEPTH IN METERS
269   COL 29-36: TURBIDITY IN JTU, SURFACE.
270   COL 37-46: TURBIDITY IN JTU, BOTTOM.
271   HTU102180     25113309   01001        .5
272   HTU102180     25063256   02 01        .4
273   HTU102180     24223308   03017        .6      15.0
274   HTU102180     24093230   04015        .6        .2
275   HTU102180     24173155   05001        .2
276   HTU102180     23433242   07016        .4        .2
277   HTU102180     23223327   08022        .4        .2
278   HTU102180     23283401   09013        .1        .2
279   HTU102180     23283437   10007        .4        .2
280   HTU102180     22583421   11019        .3        .2
281   HTU102180     22463314   12024        .2       5.7
282   HTU102180     22153214   13022        .2        .3
283   HTU102180     22373136   14019        .4        .2
284   HTU102180     22413056   15004        .5        .3
285   HTU102180     21213215   16023        .2        .2
286   HTU102180     20133240   17025       1.9        .4
287   HTU102180     20093331   18001       1.1
288   HTU102180     19183322   19026        .3        .2
289   HTU102180     19133425   20007        .3
290   HTU102180     19103549   21025        .6        .2
291   HTU102180     18283524   22005        .2        .2
292   HTU102180     18313431   23007        .3        .2
293   HTU102180     17333423   24017        .4        .4
294   HTU102180     16423433   25002        .9        .3
295   HTU102180     16593328   26009        .9       2.7
296   HTU102180     17513320   27024       2.1        .2
297   HTU102180     18403336   28024       4.4        .1
298   HTU102180     18423730   29023       2.1        .2
299   HTU102180     19233230   30024        .8        .2
300   HTU102180     19293120   31016       1.6      97.8
301   HTU102180     20263128   32024        .3        .2
302   HTU102180     21283131   33024       1.6        .2
303   HTU102180     21283057   34001        .5
304   HTU102180     20093054   35004       1.1        .3
305   HTU102180     19093058   36013       1.4        .4
306   HTU102180     18193044   37011        .8        .4
307   HTU102180     18243157   38022       4.4        .8
308   HTU102180     17273234   39019        .6        .3
309   HTU102180     17493147   40020     159.0
310   HTU102180     23053119   41003        .4        .3
311   HTU102180     17393137   42018     124.8
312   HTU070280     25113309   01001       2.9
313   HTU070280     25063256   02001       5.8       2.3
314   HTU070280     24223308   03017       1.1        .8
315   HTU070280     24093230   04014       1.7       5.2
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| | | | | | |
|---|---|---|---|---|---|
| 316 | HTU070280 | 24173155 | 05001 | 1.9 | 1.6 |
| 317 | HTU070280 | 23433242 | 07017 | 3.6 | 1.8 |
| 318 | HTU070280 | 23223327 | 08022 | 2.6 | 4.4 |
| 319 | HTU070280 | 23283421 | 09013 | 1.4 | 1.3 |
| 320 | HTU070280 | 23283437 | 10007 | 1.2 | .9 |
| 321 | HTU070280 | 22583421 | 11019 | 1.6 | 1.3 |
| 322 | HTU070280 | 22463314 | 12024 | 2.7 | 3.4 |
| 323 | HTU070280 | 22153214 | 13022 | 2.0 | 2.2 |
| 324 | HTU070280 | 22273136 | 14019 | 3.2 | 6.6 |
| 325 | HTU070280 | 22413056 | 15004 | 4.2 | 2.4 |
| 326 | HTU070280 | 21213215 | 16023 | 3.2 | 2.6 |
| 327 | HTU070280 | 20133240 | 17025 | 13.0 | .6 |
| 328 | HTU070280 | 20093331 | 18001 | | 4.2 |
| 329 | HTU070280 | 19183322 | 19026 | 3.6 | 2.9 |
| 330 | HTU070280 | 19133425 | 20007 | 3.0 | 1.8 |
| 331 | HTU070280 | 19193549 | 21025 | 2.2 | .5 |
| 332 | HTU070280 | 18283524 | 22005 | 2.0 | .7 |
| 333 | HTU070280 | 18313431 | 23007 | 3.0 | 1.9 |
| 334 | HTU070280 | 17333423 | 24017 | 3.2 | 1.1 |
| 335 | HTU070280 | 16423433 | 25002 | 6.5 | 1.6 |
| 336 | HTU070280 | 16593328 | 26009 | 4.6 | 3.0 |
| 337 | HTU070280 | 17513320 | 27024 | 3.6 | 1.3 |
| 338 | HTU070280 | 18403336 | 28024 | 2.2 | 26.0 |
| 339 | HTU070280 | 18423730 | 29023 | 2.0 | |
| 340 | HTU070280 | 19233230 | 30024 | 2.3 | |
| 341 | HTU070280 | 19293120 | 31016 | 5.3 | 1.2 |
| 342 | HTU070280 | 21283131 | 33024 | | 3.2 |
| 343 | HTU070280 | 21283057 | 34001 | 2.6 | |
| 344 | HTU070280 | 20403054 | 35004 | 2.9 | 3.2 |
| 345 | HTU070280 | 19093058 | 36013 | 2.3 | 1.7 |
| 346 | HTU070280 | 18193044 | 37011 | 2.3 | 5.0 |
| 347 | HTU070280 | 17273234 | 39019 | 3.4 | 2.1 |
| 348 | HTU070280 | 17493147 | 40020 | 2.6 | 1.2 |
| 349 | HTU012681 | 25113309 | 01005 | 1.9 | 1.9 |
| 350 | HTU012681 | 25063256 | 02001 | 4.5 | |
| 351 | HTU012681 | 24223308 | 03014 | | 7. |
| 352 | HTU012681 | 24093230 | 04015 | | 4.5 |
| 353 | HTU012681 | 24173155 | 05008 | 5. | |
| 354 | HTU012681 | 23503209 | 06001 | | 3.7 |
| 355 | HTU012681 | 23433242 | 07012 | 5.5 | 2.5 |
| 356 | HTU012681 | 23223327 | 08022 | 2.6 | 2.7 |
| 357 | HTU012781 | 23283401 | 09014 | 6.8 | 7.1 |
| 358 | HTU012781 | 23283437 | 10007 | | 31. |
| 359 | HTU012781 | 22583421 | 11010 | 6. | 7.7 |
| 360 | HTU012781 | 22463314 | 12023 | | 9.3 |
| 361 | HTU012781 | 22153214 | 13025 | 5.5 | 4.2 |
| 362 | HTU012781 | 22273136 | 15004 | 2.9 | 2.8 |
| 363 | HTU012781 | 21213215 | 16019 | | 5.8 |
| 364 | HTU012781 | 20133240 | 17025 | 6.5 | 5.2 |
| 365 | HTU012781 | 20093331 | 18004 | 2.1 | 6. |
| 366 | HTU012881 | 19183332 | 19027 | 1.7 | 2.3 |
| 367 | HTU012881 | 19133425 | 20008 | 2.8 | 2.8 |
| 368 | HTU012781 | 19103549 | 21030 | 1.8 | 2.4 |
| 369 | HTU012881 | 18283524 | 22009 | | 1.9 |
| 370 | HTU012881 | 18313431 | 23009 | 3. | 2.2 |
| 371 | HTU012881 | 17333423 | 24023 | | 3.1 |
| 372 | HTU012881 | 16423433 | 25002 | 3.6 | 3.5 |
| 373 | HTU012981 | 16593328 | 26010 | 5.5 | 5.3 |
| 374 | HTU012981 | 17513320 | 27015 | 3.6 | 5.2 |
| 375 | HTU012981 | 18403336 | 28027 | 3. | 2.5 |
| 376 | HTU012981 | 18423730 | 29 | | |
| 377 | HTU012981 | 19233230 | 30025 | 5.3 | 2.5 |
| 378 | HTU012681 | 19293120 | 31 | | |
| 379 | HTU012981 | 20263128 | 32023 | 5.9 | 95. |
| 380 | HTU012981 | 21283131 | 33023 | 3.5 | 3. |
| 381 | HTU013081 | 21283057 | 34002 | 3.7 | 4.5 |
| 382 | HTU013081 | 20493054 | 35 | | |
| 383 | HTU013081 | 19093058 | 36 | | |
| 384 | HTU013081 | 18193044 | 37005 | 5.8 | 8.1 |
| 385 | HTU013081 | 18233157 | 38023 | | 3.3 |
| 386 | HTU013081 | 17273234 | 39019 | 3.8 | 6.3 |
| 387 | HTU013081 | 17493147 | 40004 | 76. | 66. |
| 388 | HTU050481 | 25113309 | 01001 | 5. | |
| 389 | HTU050481 | 25063256 | 02001 | 5.4 | |
| 390 | HTU050481 | 24223408 | 03012 | 4.1 | 2.5 |
| 391 | HTU050481 | 24093230 | 04015 | 3.0 | 1.5 |
| 392 | HTU050481 | 24173155 | 05008 | 4.0 | 2.3 |
| 393 | HTU050481 | 23503200 | 06001 | 3.8 | |
| 394 | HTU050481 | 23433242 | 07015 | 3.5 | 2.3 |

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HTU050481      23523327  08020      1.6      1.7
HTU050481      23283401  09022      3.1      2.2
HTU050481      23283437  10005      2.2      1.3
HTU050481      22583421  11017      1.5      4.6
HTU050481      22063314  12024      5.7      2.6
HTU050481      22153214  13024      6.8      2.4
HTU050481      22273136  14014      3.3      7.3
HTU050481      22413056  15001      4.3
HTU050481      21213215  16019      5.5      3.
HTU050481      20133240  17025      3.6      5.
HTU050481      20093331  18001      5.3
HTU050481      19183322  19024      7.7      4.0
HTU050481      19133425  20011      4.2      4.
HTU050481      19103549  21020      6.6      2.8
HTU050481      18283524  22005      3.8      1.2
HTU050481      18313431  23001      4.
HTU050481      17333423  24015      4.       4.2
HTU050481      16023433  25001      2.1
HTU050481      16593324  26001      3.5
HTU050481      17513320  27024      4.2      4.1
HTU050481      18033336  28027      3.6     55.
HTU050481      18023730  29022      5.8      3.3
HTU050481      19233230  30029      3.2      2.
HTU050481      19293120  31017      8.      15.
HTU050481      20263128  32021      5.4      3.1
HTU050481      21283131  33033      4.2      6.0
HTU050481      21283057  34001      3.8
HTU050481      20093054  35004      5.4      7.5
HTU050481      19093058  36013      9.9      2.2
HTU050481      18193044  37010      4.4      4.0
HTU050481      18233157  38021     21.       3.3
HTU050481      17273234  39014     83.       5.3
HTU050481      17493147  40001    430.
HTU050481      23053119  41002     19.       2.9
HTU050481      17303137  42001    370.
HTI: HARMONIC TIDE COMPONENTS.
COL  4- 9: MONTH-DAY-YEAR OF REFERENCE TIME (T=0) FOR HARMONIC CONSTANTS
COL 10-13: TIME OF DAY FOR REFERENCE TIME
COL 14-17: LATITUDE MINUTES AND SECONDS, 10 DEGREES UNDERSTOOD.
COL 18-21: LONGITUDE MINUTES AND SECONDS, 75 DEGREES UNDERSTOOD.
COL 22-25: STATION NAME
COL 26-38: FREQUENCY, DEGREES/HOUR.
COL 39-58: COSINE AMPLITUDE
COL 59-71: SINE AMPLITUDE
HTI07228009002253400BOGR       28.9841             6.522     -3.077
HTI07228009002253400BOGR       13.943             -2.921      3.788
HTI07228009002253400BOGR       15.0411           -12.07       0.9887
HTI07228009002253400BOGR       14.9589             0.1935    -6.629
HTI07228009002253400BOGR       30.0                1.176      0.9794
HTI07228009002253400BOGR       28.4397            -3.265     -0.3431
HTI07228009002253400BOGR       13.3987             1.468      0.6903
HTI07228009002253400BOGR       15.5854            -1.155      0.5164
HTI09168010301918350BOCH       28.9841            -6.930     -0.3405
HTI09168010301918350BOCH       13.943              2.214      4.2027
HTI09168010301918350BOCH       15.0411            -1.412      5.779
HTI09168010301918350BOCH       14.9589             0.0678     0.6896
HTI09168010301918350BOCH       30.0               -0.0196    -2.220
HTI09168010301918350BOCH       28.4397             2.627      2.084
HTI09168010301918350BOCH       16.1391             0.2405     0.2878
HTI09168010301918350BOCH       13.3987             0.5595    -0.8227
HTI09168010301918350BOCH       15.5854            -0.4156    -0.0587
HRC: RECORDING CURRENT METER.
COL  4- 9: MONTH-DAY-YEAR OF START TIME
COL 10-13: START TIME
COL 14-17: LATITUDE MINUTES AND SECONDS, 10 DEGREES N UNDERSTOOD.
COL 18-21: LONGITUDE MINUTES AND SECONDS, 75 DEGREES W UNDERSTOOD.
COL 22-23: METER DEPTH BELOW SURFACE.
COL 24-25: CURRENT METER STATION IDENTIFICATION.
COL 26-27: SPEED IN CM/S.
COL 28-30: DIRECTION, MAGNETIC IN DEGREES.
THERE ARE 10 GROUPINGS LIKE COL 26-30 ON EVERY CARD. FOR MI EACH DATA
POINT IS SEPERATED BY 8 MINUTES.
HRC060481      21353200 4M1 07008090230802308019070230801708019080230902210015
HRC060481      21353200 4M1 10024070330802709030080340703006019080100702308012
HRC060481      21353200 4M1 12029080190904609019070241205812230421409206082 03
HRC060481      21353200 4M1 08199071990720210193102000819908207102090321603089
HRC060481      21353200 4M1 03078042260422101183031830315910138051790918904185
HRC060481      21353200 4M1 05188101920920405260519905200042070121108196082 07
HRC060481      21353200 4M1 09207032040821004193031990121303216052270023804249
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474     HRC060481     21353200 4M1  03260012540101009005050530502009024122920621803325
475     HRC060481     21353200 4M1  01027030120401612003033591034901022040200101908033
476     HRC060481     21353200 4M1  09031080060334901339043160026010120803106027090 12
477     HRC060481     21353200 4M1  10348043560400204348033500835617036070240101705038
478     HRC060481     21353200 4M1  08948050440803608047080401003605003073461035812328
479     HRC060481     21353200 4M1  12273123040632707352103320907608075050120828309017
480     HRC060481     21353200 4M1  08176102060619304189092090920907197121880921809204
481     HRC060481     21353200 4M1  10203102030719313224102030919904189071880916610150
482     HRC060481     21353200 4M1  120950714110325 6304 7282 8206 7170 8175 912712214
483     HRC060481     21353200 4M1  10169 920311210 9192 9 86 8102 8 96 81991018613195
484     HRC060481     21353200 4M1   8204 817612186 9185 8189 717812173121791215510250
485     HRC060481     21353200 4M1  12140 8 33 8 44 8  8 8 24 7 2310  0 7  3 9  6 8356
486     HRC060481     21353200 4M1   834412332 13 23 8310 724812206 8258121991221010182
487     HRC060481     21353200 4M1   8203 8193 8165 9179121751217610193 9210 820610207
488     HRC060481     21353200 4M1  12190102091019912196 9197102111020310206122 10 8206
489     HRC060481     21353200 4M1  12195101921218310178 3113 8 80 8 8312113 7 9912 98
490     HRC060481     21353200 4M1   918512 5510 53 1 16 4 33 4353 4307 4337 5 27 9 24
491     HRC060481     21353200 4M1   6332 330310294 4299 4272 6258 3262 4234 3240 0176
492     HRC060481     21353200 4M1   1182 7182 4183 7160 6188 7220 9213 8202 6216 3242
493     HRC060481     21353200 4M1   1 12 5 10 5 44 9 38 6 23 3 24 9 20 5 13 5 10 6  3
494     HRC060481     21353200 4M1   5 15 1 12 7 12 3  8 5 16 5 12 8 16 4 27 8 27 8 26
495     HRC060481     21353200 4M1  10 1612  610  812  510  5 8  9 9355 7355123501 0355
496     HRC060481     21353200 4M1  12  5 7  9 9  8 5 12 7 15 9 38 3 3311  8 7 26 8 79
497     HRC060481     21353200 4M1  1016612 44 9 2010 13 3353 7 30 8 3710334 735312346
498     HRC060481     21353200 4M1   7334 728710 8212342 7 34 8  3 6 47 8 44101401 0186
499     HRC060481     21353200 4M1   8192 815810158 8173 7176 8175 82021219310200 7162
500     HRC060481     21353200 4M1   515212207 8224102541023112218 8157 8 68 8 37 8 88
501     HRC060481     21353200 4M1   816410210 72211124710227 9249 8290 7282 7269 8130
@BREAK,OR
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